



Latvia University of Life Sciences and Technologies

> Annual 30<sup>th</sup> International Scientific Conference **Research for Rural Development** 2024



Latvia University of Life Sciences and Technologies

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#### LATVIA UNIVERSITY OF LIFE SCIENCES AND TECHNOLOGIES

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#### FOREWORD

The International Scientific Conference 'Research for Rural Development' is organized annually by Latvia University of Life Sciences and Technologies, this year, for the 30th time. This year the conference comprised two segments: the main conference, hosted by LBTU in Latvia on May 15-16, 2024, and a joint section held at the Tashkent Institute of Chemical Technology (TICT), which was web-streamed as part of the conference program. According to a Memorandum of Understanding, LBTU and TICT agreed to co-organize the joint section within the conference framework. Participation in the joint section was exclusive to participants from TICT.

The conference brought together scientists from several countries to present their research papers. A total of 52 studies were presented at the main conference, and 8 studies were presented online by representatives of the Tashkent Institute of Chemical Technology. The interdisciplinary research covered various topics, including rural development, health, innovations, forestry, machine learning, regional economics, social science, entrepreneurship, animal production, information and communication technologies, veterinary medicine, and education.

We believe that these Proceedings will be an excellent reference volume for researchers worldwide and it will stimulate further research in all the areas mentioned above.

We would like to thank all authors and reviewers for their contribution in international scientific level. The conference organizing team extends its gratitude to the employees of the IT and Scientific Equipment Centre for their excellent technical support, and to the chairpersons of the conference sections: Z. Vītoliņa, G. Mazure, R. Silakalne, I. Straupe, A. Vintere, I. Janpavle, A. Kļaviņš, and S. Shakhnoza for their effective organization and management of the sections.

We hope to see you at the Latvia University of Life Sciences and Technologies next year during the 31th International Scientific Conference 'Research for Rural Development 2025'.

Natālija Sergejeva Chairperson Annual 30th International Scientific Conference 'Research for Rural Development 2024'

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# SUSCEPTIBILITY OF FABA BEAN VARIETY 'MERKUR' TO BROADBEAN SEED BEETLE (*BRUCHUS RUFIMANUS*) IN LATVIA

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#### Abstract

The broadbean seed beetle (*Bruchus rufimanus*) is a significant pest of faba bean (*Vicia faba*) both in Latvia and in many other parts of the world. The objective of this study was to check the susceptibility of the faba bean variety 'Merkur' to the broadbean seed beetle in Latvia, comparing it with other popular varieties: 'Boxer' and 'Laura'. The trials were conducted in 2021 and 2022 at the Research and Study Farm 'Peterlauki' in Jelgava County and at a commercial farm in Cēsis County. The larval infestation rate of seeds of different varieties, the survival rate of individuals (larvae, pupae, imagines) in the seeds, as well as the percentage of seeds damaged by the pest in the yield were compared. It was observed that 'Merkur' seeds were significantly less infested than 'Boxer' and 'Laura' seeds. However, the survival rate of larvae in the seeds of 'Merkur' was similar to that in 'Laura' seeds and higher than in 'Boxer' seeds. The highest proportion of seeds damaged by the pest was found in the 'Merkur' and 'Boxer' yields, varying between 5–75% between years and trial locations. Therefore, it was concluded that the variety 'Merkur', evaluated from a practical point of view, does not differ from the other two varieties. Without taking additional plant protection measures, the percentage of seeds damaged by the broadbean seed beetle can significantly exceed the maximum limit (3%) specified in the buyers' quality criteria.

Key words: larvae, entrance holes, damaged seeds.

#### Introduction

The broadbean seed beetle (*Bruchus rufimanus*) is a major pest of various legume crops, including faba bean (*Vicia faba*), in the largest part of its range. Without taking measures to control this pest, 70...80% yield losses should be expected (Segers *et al.*, 2021; Gailis *et al.*, 2022). The seeds damaged by the seed beetle not only lose their nutritional value, but also become less valuable as a sowing material. The damaged seeds are significantly more susceptible to various pathogens, which, together with mechanical damage, reduce the germination rate. Plants grown from damaged seeds have lower biomass, shorter stems and roots (Almogdad, Jonaviciene, & Semaskiene, 2023; Huber *et al.*, 2023).

Recently, attention has been paid to the development of a successful integrated pest management strategy in the faba bean crops (Stoddard *et al.*, 2010). One of the preventive measures in controlling harmful organisms is the use of low-susceptible or completely resistant varieties. Currently, several DNA markers are known that are responsible for the resistance of the faba beans to some harmful organisms, such as broomrapes (*Orobanche* spp.) and *Ascochyta*-caused blight, but not to arthropod pests (Rubiales & Khazaei, 2022). However, research continues to test the susceptibility of different varieties to the broadbean seed beetle, as well as to search for new genetic lines that would be as resistant as possible to this pest (Segers *et al.*, 2022; Dell'Aglio & Tayeh, 2023).

So far, in Europe, properties that reduce the susceptibility to the broadbean seed beetle have been studied in various faba bean varieties. For example, plants of the varieties 'Côte d'Or' (France) and 'Nova Gradiska' (Croatia) have increased mechanical strength, which reduces the ability of the seed beetle larvae to bore into them. The seeds of the variety 'Quasar' (United Kingdom) contain secondary metabolites that inhibit the development of pest larvae (Carillo-Perdomo

*et al.*, 2019). Therefore, the broadbean seed beetle infests the seeds of these varieties in relatively small quantities. All of these are winter varieties and are successfully grown in European regions with a distinctly Atlantic climate (mild and rainy winters) or an arid Mediterranean climate, where the cultivation of spring varieties is almost impossible due to long drought periods during the summers.

A study conducted in the Czech Republic analysed the susceptibility of several faba bean varieties (mostly spring varieties) to the broadbean seed beetle. It was found that the highest mortality of eggs and young larvae and, therefore, the least damaged yield can be observed in the sowings of two varieties - 'Merkur' and 'Melodie'. 'Merkur' is a medium-early spring variety developed in the Czech Republic with high yields and moderately good resistance to fungal diseases. However, 'Melodie' is a medium-early spring variety created in France. It is characterized as high yielding, low in vicine/convicine and high in seed protein. Broadbean seed beetle egg, larval and pupal mortality approaching 99% of the number of eggs laid on pods was observed in both varieties (Seidenglanz & Hunady, 2016). Both varieties have been tested in different European regions to check their growth and vield performance under different environmental conditions. Such testing has also been carried out in Estonia. As a result, it has been concluded that the variety 'Merkur' is suitable for growing in continental environmental conditions, which also prevail in Latvia. The performance indicators (e.g. amount of the yield, nutritional value) of this variety in such growing conditions do not significantly differ from the indicators of the relatively widely grown variety 'Fuego' in our country. However, 'Melodie' is not suitable for growing in the environmental conditions of the Baltic region, even though the amount of seed yield sometimes does not differ from the yield of 'Merkur' and 'Fuego' (Flores et al., 2013).

The objective of our study was to compare the susceptibility of the faba bean variety 'Merkur' and other faba bean varieties to the broadbean seed beetle in Latvia. The following tasks were implemented:

1) The comparison of the infestation rate of seeds of different varieties with the broadbean seed beetle's larvae;

2) The comparison of the survival rate of the seed beetle individuals (larvae, pupae, imagines) within the seeds of different varieties during the vegetation season;

3) The comparison of the proportion of the pestdamaged seeds in the yield among different varieties.

#### Materials and Methods

The study was conducted in the vegetation seasons of 2021 and 2022. In the first season, one trial was set up at the Latvia University of Life Sciences and Technologies Research and Study Farm 'Peterlauki', Jelgava County, Platone Parish (coordinates of the trial site: 56°32'41.6"N 23°43'50.5"E). That year, three varieties – 'Merkur', 'Laura' and 'Boxer' – were compared for their susceptibility to the broadbean seed beetle. In 2022, two trials were set up: at the Research and Study Farm 'Peterlauki' (coordinates of the trial site: 56°32'47.3"N 23°43'25.8"E) and at a commercial farm in Ligatne Parish, Cesis County (coordinates of the trial site: 57°12'56.8"N 25°01'26.8"E). In that growing season, two field bean varieties were compared: 'Boxer' and 'Merkur'.

In the fields where the trials were set up, the pre-crop was spring barley (Hordeum vulgare). The main soil treatment was ploughing to a depth of 18-20 cm. The beans were sown at a depth of 5 cm on 14 April 2021. In 2022, the sowing was performed on 12 and 20 April in the Research and Study Farm and the commercial farm, respectively. The applied sowing rate was 50 germinate able seeds m<sup>-2</sup>. Each variety was sown in four replicates; each experimental plot was 30 m<sup>2</sup>  $(3 \times 10 \text{ m})$  in size. The grids of experimental plots were located inside the commercial faba bean fields. The narrowest place between the plots and the edge of the field was 30 m wide. During the growing seasons, the experimental plots were treated with plant protection products simultaneously with the surrounding bean fields, according to traditional agricultural practices. The exception was insecticides, which were not applied in the experimental plots.

In 2021, when the first seed beetle eggs were observed on pods at the lowest level of plants (29 June), pods were sampled once a week. At each sampling, nine pods from each plant level were randomly collected from each plot. Later in the laboratory, entrance holes of the broadbean seed beetle larvae, as well as individuals (larvae, pupae, imagines) and exit holes of imagines in each seed, were counted. The pods were last collected and the seeds were analysed on 17 August. In total, 135 pods were collected and analysed in each experimental plot during the growing season. The infestation rate of the pest in seeds was assessed by counting larval entry holes; each entrance hole was assumed to be created by a single larva that successfully penetrated the seed. Each seed was considered as one replicate for the mathematical analysis of the data to compare the susceptibility of the varieties.

The survival rate of the pest's individuals in seeds was calculated as the percentage ratio between the sum of individuals found in all seeds and the sum of larval entrance holes. Initially, in the first sampling times, the sum of surviving individuals in the seeds was only the number of larvae. In subsequent samplings, the number of pupae, imagines and exit holes was also added to the number of larvae.

The beans were harvested on 5 September. From each plot, 500 seeds were randomly taken, which were used to determine the proportion of seeds damaged by the seed beetle in the yield. The seeds were considered damaged if at least one broadbean seed beetle imago was noticed inside of them or they had at least one exit hole.

In 2022, only the proportion of seeds damaged by the broadbean seed beetle in the yield was analysed, comparing both varieties. This was done similarly to 2021, with 500 seeds randomly taken from each plot after the harvest.

Observations obtained at local meteorological stations showed that in 2021, there was a drought in the second half of April and the first ten-day period of May - the amount of precipitation was a few millimetres in 30 days. The average air temperature was 14.4 °C, significantly higher than the long-term average. Suitable growing conditions for faba beans prevailed only in the second and third ten-day period of May, when the total amount of precipitation was 50.2 mm, and the average air temperature was 13.1 °C. Drought also prevailed in June and July, with 15 mm and 5 mm precipitation, respectively, while the average air temperature was 5.2 °C higher than the long-term average. As a result, faba beans did not develop the upper third pods.

In 2022, meteorological conditions were more suitable for the faba bean development. In April, during the sowing, the average air temperature was 0.5 °C higher than the long-term average. The amount of precipitation in the Farm 'Peterlauki' corresponded, but in the commercial farm, it was five times less than the long-term average. In the subsequent months of the vegetation period, the amount of precipitation in both research locations was similar or slightly higher than the long-term average, but the average air temperature exceeded the long-term observations by 3...4 °C. Therefore, in the second year of the study, faba beans could fully develop.

The resulting data were processed using MS Excel 2016 with Daniel's XL Toolbox NG plug-in (version 7.3.4). Descriptive statistics (arithmetic means, standard errors) were obtained with it, as well as

ANOVA with Bonferroni-Holm post hoc test was performed.

#### **Results and Discussion**

#### Level of seed infestation

The first pods were sampled and analysed on 29 June 2021. They had developed in the lower third of the stems, and broadbean seed beetle eggs were found on them. Seven days later (6 July) pods of the middle third had also developed. The pods in the upper third of the stems did not develop for plants of any variety in the vegetation season of 2021; this is explained by the insufficient amount of precipitation in the spring and the first two months of summer.

The highest number of larval entrance holes in the seeds was observed on the third sampling (13 July), when it was significantly higher than that observed in the first two weeks. After that, it did not increase significantly and slightly fluctuated in the plots of any variety (Table 1), which indicates that at that moment, intensive broadbean seed beetle egg laying had already ended. The egg-laying period of this species is believed to last usually six weeks (Segers *et al.*, 2021). However, studies conducted in Latvia show that the egg-laying period usually lasts 4–5 weeks, reaching its peak in the third week (Gailis *et al.*, 2022).

Fluctuations in the number of larval entrance holes after reaching the peak could be explained by several factors. This could be the uneven distribution of the broadbean seed beetle population in the experimental plots, resulting in the collection of pods with slightly different levels of infestation at different samplings. Also, this result could be determined by different survival success of eggs and newly hatched larvae on different plants.

Comparing the studied varieties, it should be concluded that the seeds of 'Merkur' were significantly less infested than the seeds of the other two varieties. This trend appeared especially well in the first three weeks of observation, when the number of larval entrance holes in 'Merkur' seeds was approximately two to three times less compared to 'Boxer' and 'Laura' seeds (Table 1). It has already been studied that 'Merkur' is a faba bean variety, on the pods of which broadbean seed beetle females lay eggs in a smaller amount than on the pods of other varieties ('Boxer' and 'Laura' were not examined in that study). Similarly, 34-45% of laid eggs and first instar larvae die on 'Merkur' pods and in pod valve tissues, which has been significantly more compared to various other faba bean varieties (Seidenglanz & Hunady, 2016).

Table 1

The average number of *Bruchus rufimanus* larval entrance holes in the seeds of three faba bean varieties in the vegetation season of 2021

The date (the phenological developmental stage of plants according to BBCH-scale)	Merkur	Boxer	Laura
29 June (68–71)	0.28 <sup>a</sup> A	1.02 <sup>a</sup> <sub>B</sub>	0.80 <sup>a</sup> <sub>B</sub>
6 July (71–74)	0.53 <sup>a</sup> A	1.23 <sup>a</sup> <sub>B</sub>	1.20 <sup>a,d</sup> B
13 July (71–75)	1.39 <sup>b</sup> A	2.16 <sup>b</sup> <sub>B</sub>	2.40 <sup>b</sup> <sub>B</sub>
20 July (75–80)	1.36 <sup>b</sup> A	1.88 <sup>b,c</sup> <sub>B</sub>	1.66 <sup>c,d</sup> <sub>A,B</sub>
27 July (80–85)	1.36 <sup>b</sup> A	1.78 <sup>b,c</sup> <sub>B</sub>	1.93 <sup>c</sup> <sub>B</sub>
3 August (85–87)	1.05 <sup>b</sup> A	1.41 <sup>c</sup> <sub>B</sub>	1.48 <sup>d</sup> B
10 August (87–88)	1.26 <sup>b</sup> A	1.49 <sup>c</sup> A	1.37 <sup>d</sup> A
17 August (89)	1.16 <sup>b</sup> A	1.50 <sup>c</sup> <sub>B</sub>	1.39 <sup>d</sup> <sub>A,B</sub>

Note: lowercase letters (a, b, c, d) indicate significantly different (p<0.05) values among various dates within each variety; uppercases letters (A, B) indicate significantly different values among the varieties in each date of observations.

# The survival rate of B. rufimanus individuals inside the seeds

Larvae were detected in the seeds of all varieties already on 29 June, while the first pupae – on 27 July. At the same time, the first imagines and their exit holes were also observed in the seeds of the variety 'Merkur', but in the seeds of other varieties, the first imagines were detected a week later – on 3 August. On the same date, the first imago exit holes were also observed in 'Boxer' seeds, while in 'Laura' seeds they were first detected on 10 August. No phenological regularities were observed when assessing the survival success of broadbean seed beetle individuals infesting seeds. The percentage ratio of the number of individuals in the seeds found on 29 June to the number of larval entrance holes did not change significantly until the end of the observation period on 17 August (Table 2). Therefore, data on the seed beetle survival rates obtained from all observation dates were pooled into common sample sets, and the growing season average was calculated and compared between the varieties. Of the number of larvae that initially infested the seeds, 58.9% of broadbean seed beetle individuals survived in 'Merkur' seeds, 48.4% in 'Boxer' seeds and 54.3% in 'Laura' seeds. A statistically significant difference (p=0.014) existed between 'Merkur' and 'Boxer'. No statistically significant differences in the survival rate of individuals were found between the other pairs ('Merkur' – 'Laura' (p=0.305) and 'Boxer' – 'Laura' (p=0.117)) of varieties.

Factors that could cause the mortality of broadbean

seed beetle larvae and pupae in legume seeds are still not fully understood. Therefore, it is difficult to judge what effect varieties might have on mortality rates. Several authors have found that the infestation of various legume seeds by Bruchus seed beetles is negatively correlated with the content and concentration of iron, manganese, phenols, tannins and other chemical compounds (Mohamed & Abd-El Hameed, 2014; Tsialtas et al., 2020; Boulata, Irakli, & Tsialtas, 2022). However, these studies mostly show that the chemical composition of pods and seeds prevents seed beetle larvae from entering the seeds, causing their death at an early stage of development. On the other hand, it is not yet possible to make such a convincing conclusion about the mortality of larvae in later stages of development, which have managed to enter the seeds. Larval mortality can be caused by cannibalism. This has been observed in pea seed beetle (Bruchus pisorum) populations; when one larva accidentally encounters another larva while boring its tunnel, it kills it by partly eating it (Larson, Brindlay, & Hinman, 1938). This species is a close relative of the broadbean seed beetle, so similar behaviour could

be present. Larvae are more likely to kill each other in more infested seeds. This could explain the lowest individual survival rate in 'Boxer' seeds, as they had the highest number of larval entrance holes. However, for now, this should only be considered a hypothesis, as neither our study nor any other study can confirm it. The broadbean seed beetle larvae and pupae are regularly parasitized by the parasitoid braconid wasps Triaspis thoracicus and T. luteipes (Medjdoub-Bensaad et al., 2015; Seidenglanz & Huňady, 2016; Tsialtas, Irakli, & Lazaridou, 2018; Tsialtas et al., 2020; Boulata, Irakli, & Tsialtas, 2022). Little data is available on the distribution of these species in Europe, but they could also be found in Latvia. Observations show that traces of parasitoid activity – exit holes – are less frequently observed in legume seeds whose chemical composition repels seed beetles (Boulata, Irakli, & Tsialtas, 2022). However, likely, this is primarily related to a smaller food base of the parasitoid rather than to the characteristics of the legume variety, which, by attracting or repelling the natural enemy, promotes or reduces the survival rate of the seed beetle larvae and pupae.

Table 2

The survival rate (%) of *Bruchus rufimanus* individuals in the seeds of three faba bean varieties during the 2021 growing season

The date (the phenological developmental stage of plants according to BBCH-scale)	Merkur	Boxer	Laura
29 June (68–71)	66.7	43.1	73.2
6 July (71–74)	67.3	51.0	54.2
13 July (71–75)	52.3	53.4	44.4
20 July (75–80)	56.3	50.8	54.6 <sup>b</sup>
27 July (80–85)	42.3	30.9	30.2ª
3 August (85–87)	55.0	40.3	53.6
10 August (87–88)	64.1	59.5	57.2
17 August (89)	67.3	58.34	66.9 <sup>a,b</sup>

Note: lowercase letters (a, b) indicate two pairs of dates (pair a and pair b) for variety 'Laura' between which there were significant (p<0.05) differences; no significant differences were observed among other pairs of dates for all varieties.

#### The rate of the seed yield damage

The percentage of faba bean seed yield damaged by the broadbean seed beetle was significantly different in the two years of the study. In the 2021 season, it was in the range of 57–75%, while in 2022, the proportion of damaged seeds in the yield fluctuated in the range of 4.5–9.5%. No statistically significant differences were found between the volume of damaged seeds of 'Merkur' and 'Boxer' in both years. However, in 2021, the percentage of damaged seeds in the yield of 'Laura' was significantly lower than that of the other two varieties (Table 3).

The percentage of damaged seeds found in our study was similar to that observed previously both in Latvia and in other places where the broadbean seed beetle is a significant pest of faba beans (Segers *et al.*, 2021; Gailis *et al.*, 2022). We cannot explain with absolute certainty the large variation in the percentage of

damaged seeds between the years. But one reason could cause differences in faba bean plant development. In 2021, during the first half of the growing season, plants suffered from drought, as a result of which the plants did not develop the pods in the upper third of the stems. In contrast, in 2022, the amount of precipitation was sufficient, and the plants successfully developed pods in all thirds of the stem. Pods in the upper third are significantly less infested than pods in the lower third, where the number of infested seeds is always the highest (Gailis et al., 2022). Therefore, if plants develop pods in all thirds of the stem, the yield may have a higher proportion of intact seeds. This is unlikely to have been the only factor responsible for the differences. Fluctuations in the density of broadbean seed beetle populations between different years are also possible, but no studies are yet available on these.

The proportion of damaged seeds in the harvest is the most important indicator from a practical point of view. In Latvia, the requirements of different buyers tend to vary, however, usually, no more than 3% of damaged seeds are allowed in the material of the first food group faba beans. In the material of the second food group, the proportion of seeds damaged by pests should not exceed 4–6%. The results of our research show that it is impossible to achieve such indicators in

the seed yield of the 'Merkur' variety in Latvia without applying pest control measures. 'Merkur' was less susceptible to the broadbean seed beetle (fewer larval entrance holes) compared to the other two varieties. However, the number of larvae entering the seeds and their survival success were sufficient for the percentage of damaged seeds in the yield to be as high as or higher than for 'Boxer' and 'Laura'.

Table 3

Percentage of seeds damaged by *Bruchus rufimanus* in the faba bean yield obtained in three field trials in 2021 and 2022

	2021 (Fa	rm `Peterla	auki')	2022 (Farm	'Peterlauki')	2022 (Commercial Farm)	
	Merkur	Boxer	Laura	Merkur	Boxer	Merkur	Boxer
Mean	74.7 <sup>a</sup>	70.8 <sup>a</sup>	57.4 <sup>b</sup>	4.5 <sup>a</sup>	9.4 <sup>a</sup>	7.9 <sup>a</sup>	6.3 <sup>a</sup>
Standard Error	5.1	3.6	2.1	1.8	2.2	1.9	2.1

Note: lowercase letters (a, b) indicate significantly different (p < 0.05) values in each farm within each year.

#### Conclusions

- 1. The seeds of the faba bean variety 'Merkur' were infested by significantly fewer broadbean seed beetle larvae compared to 'Boxer' and 'Laura'. Judging by this factor, 'Merkur' was less susceptible to the broadbean seed beetle compared to the other two varieties.
- The survival success of the broadbean seed beetle individuals (larvae, pupae) that entered the seeds differed significantly between the varieties 'Merkur' and 'Boxer'. In the seeds of 'Merkur', the largest part of all the larvae that entered them developed to the imago stage. Between the other two variety pairs ('Merkur' – 'Laura' and 'Boxer' – 'Laura') no significant differences in the survival rate of the seed beetle individuals were observed.
- 3. The highest proportion of damaged seeds was found in the yield of 'Merkur' and 'Boxer'; it was significantly lower in the yield of 'Laura'. In the agroecological conditions of Latvia, without pest control, the yield of 'Merkur' may contain 5–75%

of seeds damaged by the broadbean seed beetle. This amount of damaged harvest is greater than the maximum allowable proportion of damaged seeds specified in the buyers' quality criteria.

4. In Latvian conditions, the faba bean variety 'Merkur' showed less susceptibility to the broadbean seed beetle during the vegetation period, when the pest lays eggs and first instar larvae penetrate the seeds. However, this is of no practical significance as the percentage of damaged seeds in the yield was similar or higher than other varieties.

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# OCCURRENCE OF FRUIT AND LEAF DISEASES ON JAPANESE QUINCE (CHAENOMELES JAPONICA) IN LATVIA

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#### Abstract

Japanese quince (*Chaenomeles japonica*) is a minor but prospective fruit crop due to the value of fruits and suitability for processing. Research aimed to clarify the incidence of quince leaf and fruit diseases depending on the year and plantation and determine the critical periods of diseases. The study was conducted from 2017 to 2019 in eight commercial Japanese quince plantations across different regions of Latvia. The incidence (%) of leaf and fruit spots and fruit rot was assessed several times during vegetation period. Considerable rot development was observed in only the first year of the study. The incidence of fruit rot in the middle of 2017 ranged from 0.7 to 11.7% depending on the plantation, while in 2018–2019 did not exceed 2% in any of the plantations. The critical period of fruit rot development was determined in the middle of fruit development and time closer to ripeness. Development of fruit spots increased closer to ripeness. In 2017, the incidence of leaf spots reached high levels at the end of the vegetation periods (21–100% depending on year and plantation). The most critical periods of leaf spots of leaf spot development were the end of fruit development and full ripening of fruits. Determination of the critical periods of quince disease development could be used to create an effective and environmentally friendly disease control system. **Key words:** incidence, critical period, fruit rot, spots.

#### Introduction

Japanese quince (*Chaenomeles japonica*) is taxonomically classified within the *Rosaceae* family, *Maloidae* subfamily. Japanese quince (hereinafter – quince) has been grown in Latvia for fruit production since the fifties of the last century (Kaufmane *et al.*, 2013). Quince fruits are of high value and suitable for processing (Mierina *et al.*, 2011; Nahorska, Dzwoniarska, & Thiem, 2014). Therefore, interest in their cultivation has increased in recent years, and quinces are regarded as a prospective crop in Latvia.

Although there are no reports about economically significant quince diseases, as the area of quince plantations increases, it is expected that the importance of diseases could also increase, similar to other crops of the *Rosacea* family.

Quince's diseases have been poorly researched, and only a few studies have been conducted. The occurrence of diseases in Northern Europe was studied more than 20 years ago (Norin & Rumpunen, 2003) and 12 years ago in the Nacional Botanical Garden of Lithuania (Grigaliūnaitė, Žilinskaitė, & Radaitienė, 2012). The latest results on the identified quince diseases and their causal agents are shown in two studies conducted in Russia (Firsova & Rusinov, 2013; Fedulova *et al.*, 2020).

Fruit rots and leaves and fruit spots are described as quince's most essential diseases (Norin & Rumpunen, 2003). Previous studies in Latvia and other countries showed that fruit and leaf spots and fruit rot are caused by different fungi (Grigaliūnaitė, Žilinskaitė, & Radaitienė, 2012; Fedulova *et al.*, 2020; Jakobija *et al.*, 2022). Systematic observations of quince diseases have not been conducted previously in Latvia. The results of the first year of this study on the incidence of fruit rot have been previously reported by Jakobija *et al.* (2018). The results of all three years of the study, including data on the incidence of fruit rot in 2018 and

2019 and the development of leaf and fruit spots in quince plantations are analysed in current article. The presented study aims to determine the incidence of quince leaf and fruit diseases depending on the year and plantation and clarify the critical periods of diseases.

#### Materials and Methods

#### Monitoring sites and assessment of diseases

Quince diseases were assessed in Latvia's eight commercially growing farms covering all regions of Latvia between 2017 till 2019. Disease assessments in plantations of three Japanese quince cultivars ('Rondo', 'Rasa', and 'Darius') were performed at the Institute of Horticulture, Latvia University of Life Sciences and Technologies (IH); in the rest of the plantations, quince is grown by seedlings. A more detailed description of the quince plantations including a map is given in the publication of Gailis et al. (2023). Diseases were assessed twice a month in three plantations - IH (56°36'28.7"N, 23°17'57.7"E), Lubeco Ltd. (57°25'16.5"N, 22°38'50.5"E), and Cooperative Ltd. (57°25'44.8"N,25°16'31.4"E) -, and once a month in other farms: Mežvidi (56° 49'57.8"N, 21°38'15.3"E), Bulini (57°28'00.1"N, 25°50'02.7"E), Lejaskārkli (57°24'04.6"N, 25° 22'52.3"E), Elianda (57°01'45.2"N. 24°58'03.1"E), and Rāmkalni Nordeco Ltd. (57°08'37.7"N, 24° 35'44.9"E) during each growing season.

Going diagonally through the field, 20 randomly selected quince plants were examined for leaf and fruit damage associated with fungi. Five fully developed leaf rosettes (300 in each plantation) on three randomly selected shoots of each plant were chosen for assessment. Symptoms of the fungal disease were registered on 15 fruits from each plant intended for accounting (for 300 in each plantation).

The phenological growth stage (GS) of quince was

recorded at each assessment according to the BBCH scale for pome fruits (Meier, 2001) that have been adapted for quince. Data of disease incidence were ranged based on GS of quince. The incidence (%) of fruit and leaf spots and fruit rot was calculated as a formula used by Jakobija & Bankina (2018).

#### Meteorological conditions

Meteorological conditions in the vegetation season 2017 were characterised by long periods of rain. Meanwhile, the season of 2018 was hot and dry. Only at the beginning of August, close to harvest time, the amount of precipitation increased. The vegetation period in 2019 started with high air temperatures and drought. The beginning of May was cool, precipitation slightly exceeded the long-term level. The second tenday period of May was hot, and the humidity was low. The end of May was hot, with a high precipitation level. June is characterized by high air temperatures and relatively low precipitation. There is cool and very wet weather in July and at the beginning of August. The middle of August was hot with low amount of precipitation. Still, high air temperatures and precipitation were recognised in the next ten days. Gailis et al. (2023) have described meteorological conditions during these observations in more detail. Statistical processing of data

The incidence data were assessed for normal distribution using Bartlett's and the Shapiro-Wilk normality tests. These tests confirmed that the data do

normality tests. These tests confirmed that the data do not follow a normal distribution. Subsequent data analysis was conducted using nonparametric methods, specifically the Kruskal-Wallis test and Dunn's test with Bonferroni correction (with a significance level of  $\alpha$ <0.05). All statistical analyses were performed in R (version 4.1.1) and RStudio.

#### **Results and Discussion**

Various symptoms of diseases in quince have been previously detected and described (Jakobija *et al.*, 2022).

#### Fruit rot

*Botrytis cinerea* and *Monilinia* species are considered important causal agents of quince fruit rot in Sweden and Russia (Norin & Rumpunen, 2003; Fedulova *et al.*, 2020). Also, fungi from the genera *Botrytis* and *Monilinia* have been isolated from rotted quince fruits in Latvia (Jakobija *et al.*, 2022).

The first symptoms of fruit rot appeared at the beginning of fruit development. In 2017, the highest incidence of disease was observed when fruits reached 40–80% of final size (GS 74–78), fluctuating from 0.7 to 11.7% depending on the plantation. Closer to harvest, fruit rot incidence decreased, by around 1%, because previously rotted fruits had fallen off. However, a week later, in plantation Lubeco, where the last harvest was due, fruit rot incidence extended to 12.3%. Based on this, it can be hypothesized – timely and random harvesting is an important measure to decrease fruit rot development. Differences in fruit rot incidence among the plantations in this season were not statistically significant (Jakobija & Bankina, 2018).

Due to drought at the beginning of 2018, fruit rot occurred late and only in some plantations. Close to the harvest period, when humidity rapidly increased, cracking of fruits was observed in IH. Cracks promoted the development of fruit rot and resulted in the highest incidence in comparison with the rest of the plantations, however, it did not exceed 2%.

The first rot symptoms on young fruits were detected early in season 2019 - at the beginning of June when quince fruits reached 40–50% of final size (GS 74–75). Nevertheless, due to hot and dry weather conditions, there was no observed increase in fruit rot incidence. The overall incidence of fruit rot before harvesting fluctuated within 1–2%, depending on the plantation.

Considering these results, it can be concluded that the most critical periods of fruit rot development were the middle of fruit development (GS 75) and the time closer to harvest (GS 85–89).

#### Fruit spots

Several genera of fungi (most frequently – Alternaria, Fusarium, Monilinia, and Neofabraea) have been found in fruit spots of quince in Latvia (Jakobija, Bankina, & Klūga, 2022). In Sweden, the Cladosporium, Alternaria, Penicillium, Neofabraea, Phoma, and Septoria species are isolated from fruit spots (Norin & Rumpunen, 2003).

Spots associated with fungal damage appeared on fruits when they reached final size (GS 79) and started to ripen (GS 81) at the beginning of August of 2017. Development of fruit spots increased closer to ripeness (GS 87–89), and the incidence of disease fluctuated from 0.7–44% depending on the plantation (Table 1).

In plantations Buliņi and Elianda, the first signs of fruit spots in the vegetation period 2018 were detected earlier than in the previous season – during the fruit's second fall (GS 73). However, the increase in spot incidence did not continue for the whole of June due to dry weather. In addition, a drop of infected fruits was detected. Fruit spot development resumed in IH in the middle of July when fruits started to ripen (GS 81), and in the middle of August, they were detected in all plantations. Changes in the development of the disease could be explained by the increase in precipitation level at the beginning of August. The incidence of fruit spots closer to harvest time reached 7.7–46.0%, depending on the plantation (Table 1).

Despite the early disease appearance in 2019, the incidence of fruit spots increased slowly during the 2019 season because the weather was dry. Closer to harvest time the incidence of fruit spots grew, in IH and Lubeco reached 13.0-24.0%, and was lower in the rest of the plantations (0.7-6.0%) (Table1).

No significant differences in average fruit spot incidence were found among farms (p=0.91) and vegetation periods (p=0.16).

The results obtained confirmed the critical period for the development of fruit spots, which occurs during the stage of fruit ripening (GS 81–89).

uning run ripening depending on plantation										
	2017			2018			2019			
Plantation	The growth stage of quince									
	77–80	81	85–87	81-83	85	87–89	79–80	81-85	87–89	
Institute of Horticulture 'Darius'	0.0	16.3	16.7	1.3	23.7	43.0	0.0	7.3	22.0	
Institute of Horticulture 'Rasa'	0.0	15.0	12.7	2.0	13.0	46.0	3.0	16.0	24.0	
Institute of Horticulture 'Rondo'	0.0	2.0	0.7	2.7	17.3	39.0	1.7	3.7	22.3	
Farm Mežvidi	0.0	N/A	10.7	1.0	N/A	7.7	0.0	N/A	2.7	
Lubeco Ltd.	1.7	18.0	40.3	0	10.7	16.0	3.3	5.0	13.0	
Cooperative Ltd.	1.3	13.0	25.7	0	1.3	14.7	0.3	4.3	2.7	
Farm Buliņi	0.0	N/A	40.0	0.3	N/A	12.3	0.0	N/A	0.7	
Farm Elianda Ltd.	0.3	N/A	44.0	0.7	N/A	12.3	0.0	N/A	7.3	
Rāmkalni Nordeco Ltd.	0.0	N/A	70.0	0	5.0	7.7	0.3	N/A	1.3	
Farm Lejaskārkli	2.3	N/A	0.0	0	N/A	10.3	0.0	N/A	6.0	

Incidence of fruit spots (%) in vegetation periods 2017–2019 during fruit ripening depending on plantation

N/A - not assessed.

#### Leaf spots

Several fungi were detected in leaf spots of quince – mainly Alternaria, Diplocarpon, Phyllosticta, Cladosporium, and Epicoccum – in Russia and Sweden (Norin & Rumpunen, 2003; Fedulova et al., 2020). Also, fungi from genera Alternaria and Sarocladium were recognized as most specific on quince leaves in Latvia (Jakobija et al., 2022). The first symptoms of leaf spots in 2017 in some plantations appeared at the end of May during flowering (GS 61– 69). In the middle of June at the beginning of fruit development (GS 71), leaf spots appeared in all sites of observation; the incidence fluctuated from 4 to 9% depending on the plantation. It was observed that leaf spots cause premature leaf drop during the onset of fruit development. In the middle of vegetation season, leaf spot incidence was lower in IH (1.7-6.7%depending on cultivar) compared with other survey sites (8.7-30.0% depending on plantation). At the end of the season, leaf spotting reached a similar level in all quince plantations, and the incidence of disease fluctuated from 22 to 62% (Table 2).

Table 2

Table 1

	20	017	20	18	2019					
Plantation	The growth stage of quince									
	75–81	83–89	76–81	87	78-80	89				
Institute of Horticulture 'Darius'	17.0	53.7	10.33	44.67	15.3	25.0				
Institute of Horticulture 'Rasa'	19.7	31.3	5.67	62.33	3.0	24.0				
Institute of Horticulture 'Rondo'	29.0	22	3.33	11.00	7.7	35.7				
Farm Mežvidi	42.3	37.7	61.33	81.67	27.3	54.7				
Lubeco Ltd.	43.7	49.7	16.00	38.33	28.3	34.0				
Cooperative Ltd.	29.3	36.3	6.00	9.33	17.0	50.0				
Farm Buliņi	13.3	43.7	13.00	14.67	22.3	20.3				
Farm Elianda Ltd.	36.7	40.7	4.33	2.00	9.7	29.7				
Rāmkalni Ltd.	25.7	31.7	28.67	45.33	28.7	58.0				
Farm Lejaskārkli	69.7	62.7	35.67	59.33	28.7	66.7				

Incidence of leaf spots (%) in vegetation periods 2017–2019 during end of fruit development and fruit ripening depending on plantation

The first symptoms of leaf spots in the season 2018 appeared at the beginning of June in time of fruit development (GS 71–74) in most observed plantations, a little later than in the previous year. However, increasing in leaf spot development was observed only at the beginning of August when fruits were about to finish the development and started to ripen (GS 76–81) (Table 2). The high amounts of precipitation promoted the spread of disease; incidence reached high levels (21–100% depending on the plantation) close to harvest. These findings align with results obtained by Norin & Rumpunen (2003) that severity of leaf spots depends on weather conditions of the year.

The first spots on quince leaves were detected when fruits started to develop (GS 71) in 2019. The following increase in disease coincided with a rainy period in June. At the end of June (GS 75–76) and the beginning of July, when fruits reached about 80% of final size (GS 78), in several plantations incidence of leaf spots reached agronomically significant levels (about 20% and higher). Infected leaves turned yellow and fell off prematurely. This process co-occurred with fruit deve-

lopment and could be assumed to damage yield formation. Similar observations, when leaf spots initiate leaf drop in the middle of vegetation, were described in Russia in the Tambov region (Fedulova, Kuklina, & Kaštanova, 2017) and Sweden (Norin & Rumpunen, 2003). At the end of the vegetation period incidence of leaf spots reached high levels (20–66%) in all plantations (Table 2). There were no significant differences in average leaf spot incidence among years (p=0.332) and among plantations (p=0.069).

However, during the research, it was proved that average leaf spot incidence significantly differed among quince growth stages (p=0.001) 'Figure 1'. During flowering, the first spots on leaves were detected only in 2017. Therefore, the average incidence over seasons was low 'Figure 1'. The incidence of leaf spots was significantly lower at the beginning of fruit development (GS 71–74) compared to results at the end of fruit development (GS 75–79) and the beginning of fruit ripening (GS 81–85). The significantly highest incidence was observed at the end of ripening (GS 87– 89) 'Figure 1'.



Figure 1. Average quince leaf spot incidence depending on growth stage (GS) in vegetation periods 2017–2019 in all plantations.

It can be determined that critical periods of the spread of leaf spots were the end of fruit development and close to fruit maturity.

#### Conclusions

- 1. Considerable fruit rot incidence was detected only in one studied vegetation period. In the middle of 2017, the incidence of fruit rot ranged from 0.7 to 11.7% depending on the plantation, while in 2018–2019 it did not exceed 2% in any of the plantations.
- 2. The critical periods for spread of fruit rot were the middle of fruit development (GS 75) and the end of ripening (GS 85–89).
- 3. The critical period of fruit spot development is time closer to harvesting (GS 85–89). Fruit spot incidence was not influenced by the conditions of

vegetation period and farms.

- 4. The leaf spot level differed among quince growth stages. At the end of vegetation periods, the incidence of leaf spots reached 21–100%, depending on the year and plantation.
- 5. The end of fruit development (GS 75–79) and the period of full ripening of fruits (85–89) were the most critical periods of leaf spot development.

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# THE EVALUATION OF TAN SPOT PHENOTYPE AND THE PRESENCE OF NECROTROPHIC EFFECTORS IN THE POPULATION OF *PYRENOPHORA TRITICI-REPENTIS* IN LATVIA

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#### Abstract

Tan spot is an economically important disease of wheat in Latvia, but there is still insufficient information about its causal agent's *Pyrenophora tritici-repentis* diversity in Latvia. The aim of this study was to evaluate the disease phenotype in the field and the possible presence of necrotrophic effectors Ptr ToxA, Ptr ToxB and Ptr ToxC in the *P. tritici-repentis* population in Latvia. Typical differential wheat lines 'Glenlea', '6B662', '6B365' and 'Salamouni' were evaluated under the field conditions in 2023 in the central part of Latvia. The highest tan spot severity was observed during the flowering stage with no significant difference between wheat genotypes. During the experiment, the typical disease phenotypes corresponding to all three known effectors were noted. Additionally, typical tan spot symptoms were determined on the resistant cultivar 'Salamouni', confirming the presence of new, currently uncharacterised effectors that are not compatible with the existing race model. Future studies should focus on searching for new effectors and further characterising known necrotrophic effectors, as knowledge about *P. tritici-repentis* and wheat interaction is still incomplete.

Key words: diversity, differentials.

#### Introduction

Tan spot caused by *Pyrenophora tritici-repentis* is a widespread and destructive wheat foliar disease in Latvia and all major wheat-growing regions around the world (Savary *et al.*, 2019; Švarta *et al.*, 2023). The yield loss is estimated to be around 4.3–6.8%, and in some cases, it can reach up to 48% (Rees & Platz, 1983; Savary *et al.*, 2019).

Studies of *P. tritici-repentis* population variance are necessary to better understand interactions between wheat varieties and the pathogen. The diversity of *P. tritici-repentis* is still insufficiently studied in Latvia and Europe. Lamari *et al.* (2003) created the current eight-race model, which is widely used to describe *P. tritici-repentis* diversity around the globe (Ciuffetti *et al.*, 2014; Kamel *et al.*, 2019; Aboukhaddour *et al.*, 2021). Each *P. tritici-repentis* race is characterised by the presence or absence of three currently known necrotrophic effectors (NEs) – Ptr ToxA, Ptr ToxB and Ptr ToxC (Ciuffetti *et al.*, 2010). A classical differential set developed by Lamari *et al.* (2003) can exhibit two distinct symptoms – necrosis or chlorosis depending on the NEs of each *P. tritici-repentis* strain caries (Table 1). The designation of race is currently based on interaction between NEs and differentials.

Table 1

	Races/Cha	Races/Characteristic toxins											
Differentials	Race 1/ Ptr ToxA, Ptr ToxC	Race 2/ Ptr ToxA	Race 3/Ptr ToxC	Race 4/ <sup>b</sup>	Race 5/Ptr ToxB	Race 6/Ptr ToxB, Ptr ToxC	Race 7/Ptr ToxA, Ptr ToxB	Race 8/ Ptr ToxA, Ptr ToxB, Ptr ToxC					
Glenlea	S(N) <sup>a</sup>	S(N)	R	R	R	R	S(N)	S(N)					
6B662	R	R	R	R	S(C)	S(C)	S(C)	S(C)					
6B365	S(C)	R	S(C)	R	R	S(C)	R	S(C)					
Salamouni	R	R	R	R	R	R	R	R					

The reaction of differential wheat genotypes to known necrotrophic effectors of *P. tritici-repentis* (adapted from Lamari & Strelkov, 2010)

 ${}^{a}S$  – susceptible; R – resistant; (N) – necrosis; (C) – chlorosis;  ${}^{b}Race 4$  is assumed to be avirulent in the current eight race model and not carrying any of the currently known necrotrophic effectors.

Race 1 is thought to be the most widespread, while the distribution of other races depends on the region (Kamel *et al.*, 2019). The prevalence of race 1 is attributed to Ptr ToxA, which is thought to be the major virulence factor (Aboukhaddour *et al.*, 2021). Current eight race model is not complete; several authors have described new isolates which are not compatible with the existing

model (Ali, Gurung, & Adhikari, 2010; Moreno, Stenglein, & Perelló, 2015; Guo, Shi, & Liu, 2018). Pathogen diversity studies fill gaps in the current knowledge regarding the phenotypical and genotypical variance of pathogens. There is a clear indication of the existence of currently uncharacterised necrotrophic effectors in the global *P. tritici-repentis* population. Knowledge about pathogen populations and diversity can help develop specific markers and tools for agronomists and breeders to limit the economic impact of tan spot. There is almost no data about *P. triticirepentis* population and occurrence of necrotrophic effectors in Latvia.

The aim of this study was to determine the disease phenotype and possible occurrence of NEs (Ptr ToxA, Ptr ToxB and Ptr ToxC) in the Latvia's population of *P. tritici-repentis*.

#### **Materials and Methods**

A field trial was conducted in the 2023 vegetation season to assess the typical symptoms indicating the presence of Ptr ToxA, Ptr ToxB and Ptr ToxC in the local P. tritici-repentis population. Four classical differentials for P. tritici-repentis races determination, 'Glenlea', '6B662', '6B365' and 'Salamouni', were sown in 1.5 L vegetation trays, and after the seedling emergence, they were transferred to the production wheat field with cultivar 'Skagen' in central part of Latvia (56.405791 N, 23.386707 E). This region of Latvia with most intensive wheat production. Seven to eight seeds were sown in each tray. After seed germination, the seedling number per tray was rounded down to five. Vegetation trays were arranged randomized in four replicates, where one replicate contained one tray from each differential line.

During stem elongation (GS 32–33), differentials were sprayed with fungicide Flexity (metrafenone,  $300 \text{ g L}^{-1}$ ) to avoid early mildew infection. Systemic insecticide Carnadine Extra (acetamiprid, 200 g L<sup>-1</sup>) was sprayed at the booting stage (GS 47–49).

The tan spot symptom type (necrosis or chlorosis) and severity (damaged area of leaf surface, %) were evaluated on the wheat differential lines once a week starting from seedling germination till flowering stage (GS 61-65). Tan spot severity score was assessed for every plant in vegetation trays and average disease severity per replicate (vegetation tray) was calculated. Statistical analyses for tan spot severity were carried out using RStudio version 12.0 + 369 with  $\alpha = 0.05$  for all tests. Tan spot severity data corresponded to normal distribution as the dataset passed tests with QQ normal distribution graph, Shapiro-Wilk normality test and Bartlett's test. This allowed us to perform a one-way analysis of variance (ANOVA) with the same software. The differences in tan spot severity were determined using the Bonferroni test from the agricolae package (de Mendiburu, 2023).

#### **Results and Discussion**

First tan spot symptoms were observed during the late booting and early heading stage (GS 49–51). The highest severity of tan spot symptoms was recorded at the beginning of flowering (GS 61–63).

On cultivar 'Glenlea', tan spot symptoms were recognised as necrotic spots. Small chlorotic spots were typical symptoms on genotypes '6B662' and '6B365'. Cultivar 'Salamouni' also exhibited common tan spot symptoms necrosis and chlorosis – brown diamond-shaped blotches encircled by yellow oriole 'Figure 1'. Resistant genotype reaction – black dots was not observed.



Figure 1. Tan spot symptoms (marked with red circles) on cultivar 'Salamouni'.

The difference in final tan spot severity on all four genotypes was not statistically significant – 2.1% on 'Glenlea', 2.1% on '6B662', 1.6% on '6B365' and 2.2% on 'Salamouni' 'Figure 2'. The finding of typical tan spot symptoms on the cultivar 'Salamouni' is noteworthy since this cultivar is considered resistant to all three NEs of *P. tritici-repentis* (Lamari & Strelkov, 2010). Similar results were obtained by Moreno, Stenglein, & Perelló (2015), who reported isolates that induced necrosis or chlorosis on this cultivar *in vitro*. Multiple articles have been published over more than 20 years that describe isolates with novel virulence patterns on previously characterized differentials (Ali & Francl, 2002; Andrie, Pandelova, & Ciuffetti, 2007; Benslimane *et al.*, 2011), indicating the great diversity of the pathogen.

Twenty-three isolates from Lithuania and two isolates

from Romania have been found to belong to an unknown race in Europe by Abdullah et al. (2017). These isolates behaved like either race 1 or race 2 but lacked the *ToxA* gene characteristic of this race. These findings require reviewing the existing system and creating another approach to describe the virulence diversity of P. tritici-repentis. The limitations of the current race model were also noted by Lamari himself (Lamari & Strelkov, 2010), and despite the race characterization protocol improvements previously proposed by Andrie, Pandelova, & Ciuffetti, (2007), the existing model is still incomplete. The current race model is not portrayed in the complete genome data of P. tritici -repentis isolates (Moolhuijzen et al., 2018). Moolhuijzen et al. (2018) also propositioned to expand the differential set to include more widely grown

cultivars. Whole genome data probably will be the main driving force in the discovery of new virulence factors in the genome. However, this task may be challenging considering how plastic and adaptable is the genome of *P. tritici-repentis* (Gourlie et al., 2022). The disease symptom screening in the field proved the typical phenotype of all three known NEs in the local

P. tritici-repentis population. The presence of ToxA and ToxB genes was confirmed by Kaneps et al. (2022), while Ptr ToxC was determined in Lithuania's P. tritici-repentis population by Abdullah et al. (2017). Future studies should focus on known and unknown P. tritici-repentis effectors, as knowledge about wheat and pathogen interaction is still incomplete.

existing race model of P. tritici-repentis is

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of fundamental research at Latvia University of Life

incomplete and needs revision.



Figure 2. The severity of tan spot on four classical differentials for Pyrenophora tritici-repentis race determination.

#### Conclusions

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- 1. The disease phenotype related to effect of Ptr ToxA, Ptr ToxB, and Ptr ToxC was noted on race differential genotypes in the production field, indicating that all three necrotrophic effector genes are present in the local population of *P. tritici-repentis*.
- 2. Typical tan spot symptoms on the cultivar 'Salamouni' confirm the presence of new, currently uncharacterised virulence factors.
- 3. The data confirm previous statements that the

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Acknowledgements

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# TREE LITTER PRODUCTION IN CONIFEROUS OLD-GROWTH FORESTS ON ORGANIC SOILS

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#### Abstract

Canopy litterfall is a vital component of forest ecosystems, facilitating nutrient and organic carbon transfer to the soil. Understanding litterfall dynamics in forests is crucial for assessing carbon fluxes at the national level and refining carbon balance estimations. However, information about aboveground litterfall dynamics in old-growth forests remains scarce. The aim of the study was to characterize the annual litterfall carbon input in coniferous old-growth forests on drained and undrained organic soils. In total, 12 old-growth Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H. Karst) forests stands with the age range of 146 - 171 years were selected. Using cone-type litter traps, we obtained data on litterfall volumes over a one-year period. Our findings reveal that old-growth forest annual carbon input from litterfall exceeds estimates of mature forest stands aboveground litterfall. In drained sites, mean annual litter carbon input reached  $2.80 \pm 0.29$  t ha<sup>-1</sup> yr<sup>-1</sup>, while in undrained sites, it amounted to  $2.17 \pm 0.17$  t ha<sup>-1</sup> yr. Basal area and deadwood showed a close positive correlation with annual litter carbon input, underscoring the peculiarities of late successional forest stand carbon dynamics. Total stand basal area as easily measurable forest inventory parameter was the best predictor of annual litter C input for practical application. **Key words:** Canopy litterfall, carbon dynamics, drainage, overmatured forests, peat soil.

#### Introduction

Canopy litterfall of forest ecosystems is a significant component of net primary production that constitutes a fundamental pathway of carbon (C) and nutrient input to the forest floor. It has been estimated that litterfall of European forests transfer 351 Tg C, 8.2 Tg N, 0.6 Tg P and 1.9 Tg K annually (Neumann et al., 2018). In a forest ecosystem, litterfall is the main source of organic material that is forming humus and organic layers of soil. Furthermore, the chemical composition and quantities of litter are affecting soil microbial activity, litter decay rates and thus dynamics of soil organic matter (SOM) of forest soils. Litterfall storage and decomposition rates in turn has effect on C and nutrient cycling and thus affecting soil fertility. Site type has a strong effect on organic layer buildup and decomposition rates, where moisture regime is the main factor affecting these processes.

Canopy litterfall of forest ecosystem consists of diverse fractions of organic material. In general, three main fractions can be distinguished:

1. Fine litter – not always well-defined small size particles of organic matter, that includes buds, needles, leaves, barks. Needle and leaf litter production has a strong periodicity. In stands of younger age, there is a higher proportion of needle litter compared to older stands, relative to the total amount of litterfall. In a study conducted on Scots pine stands in Sweden, needle litter accounted for 83% of the total litterfall in stands aged 18-25 years. However, in older stands (120-126 years), this proportion decreased to 58%. Typically, mature stands that have reached a stable state show a decrease in annual litterfall production with minimal variation between years.

2. Branch and twig litter cannot be consistently attributed to specific periods but is rather influenced by particular weather events such as wind storms, heavy rain, or snowfall. A greater proportion of woody parts in litter is observed in middle to old stands due to increased branch mortality associated with older trees.

3. Cone litter is strongly reflecting periodicity and clear increase with increasing age of the stand.

Foliar litterfall exhibits distinct patterns among species in both boreal and temperate zones. For pines of boreal forest zone needles are shed regularly on average every 4 years with most of the litterfall (ca. 70%) occurring in the autumn. Spruce on the other hand, has completely different needle litterfall pattern, since needles can hold up to 10 years on shoots, and litterfall is continuous, meaning that needles that are located on a single shot can be of different years (Berg & Laskowski, 2006). Therefore, in contrary to pine, not all needles on a shot are shed on the same time. Spruce has no specific period at which most of needles fall, as it is for pine, so for spruce the needle shed is occurring all over the year with somewhat higher needle fall in the winter time. For both conifer species, dry periods can increase the needle litter fall. For deciduous trees, leaf litter fall is usually occurring in a short period in the autumn.

Annual litterfall production is influenced by various factors, including local and regional climate, soil nutrient status, and stand characteristics such as age, composition, and basal area. Management practices, such as fertilization (Jansone et al., 2020) and tree genetics (Matisons et al., 2019.), influence tree growth rates and consequently impact litter production variation between forest stands. Climate characteristics, including temperature and precipitation, strongly influence litter production. Litterfall in the boreal zone tends to be relatively low compared to temperate continental zones, while regions with a Mediterranean climate exhibit different litterfall patterns and quantities altogether. In a study conducted in Sweden within the boreal zone, Scots pine mean annual litterfall ranged from 530 kg ha<sup>-1</sup> year<sup>-1</sup> near the Arctic Circle to 3700 kg ha<sup>-1</sup> year<sup>-1</sup> at latitudes of 57° N (in southern Scandinavia). Under relatively similar growing conditions regarding soil fertility, needle litter fall tends to be lower in drier and

cooler climates. The lowest amount of litter fall is predominantly observed in nutrient-poor sites, where the basal area is generally low. Basal area serves as a widely utilized forest stand index, successfully employed in modeling annual litterfall within forest stands of various species and potentially at the genus level. Litterfall models are valuable tools for forecasting annual litterfall and contribute to the development of soil organic carbon models (Viskari et al., 2022). A study in Sweden effectively integrated litterfall measurements from various species, including Scots pine and Norway spruce, into the same regression model (Berg & Meentemeyer, 2011). The findings revealed that Scots pine generally produces a greater overall quantity of litter compared to Norway spruce, as measured by total litter. However, it was observed that Norway spruce tends to produce more needle litter compared to Scots pine.

Reliable data on litterfall, obtained from litter traps across different species and site types, is crucial for a wide audience, including soil scientists involved in modeling soil organic carbon and policymakers responsible for estimating greenhouse gas emissions at the national level. Recent regional studies have provided insights into litterfall dynamics on drained and undrained organic soils for various tree species highlighting notable variations in carbon input across different stand ages, particularly between young and middle-aged stands. Yet there remains a gap in understanding litter production in old-growth forests. The structure of old-growth forests, including dominant and secondary canopy layers, as well as formation, increased deadwood significantly influences overall canopy litterfall. Nutrients released from decaying deadwood influence soil nutrient status (Khan et al., 2021), which can subsequently impact

canopy litterfall production (Berg & Laskowski, 2006). This study aims to address this gap by characterizing the annual litterfall in coniferous old-growth forests on drained and undrained organic soils.

#### Materials and Methods

The research was conducted within the hemiboreal zone located in Latvia. Temperate climate is influenced by the Baltic Sea and the North Atlantic. Average annual precipitation is 692 mm and maintains a mean annual air temperature of +6.4 °C. February is the coldest month with an average air temperature of approximately -3.7 °C, while July is the warmest month, recording an average air temperature of +17.4 °C, according to data from the Latvian Environment Geology and Meteorology Centre.

In total, 3 objects were selected for each tree species and site type 'Figure 1'. Scots pine (Pinus sylvestris L.) and Norway spruce (Picea abies (L.) H. Karst) as dominant species of the forest stand were selected, where proportion of dominant species ensures at least 50% of stand composition (standing stock). Two site types with organic soils, characterized by different moisture regime, were selected for the study: an undrained site classified as Caricoso-phragmitosa and a drained site classified as Myrtillosa turf. mel. according to local forest typology (Bušs, 1997). Stand measurements and calculations of stand parameters were conducted following the local oldgrowth conifer stand characterization methodology outlined by Kenina et al. (2018). Stand characteristics of mean diameter at breast height (D, cm), tree height (H, m), basal area (G, m<sup>2</sup> ha<sup>-1</sup>), standing stock (M, m<sup>3</sup> ha<sup>-1</sup>) and stand density (N, trees per ha<sup>-1</sup>) for dominant and secondary canopy layer (Table 1).



Figure 1. Research objects.

Table 1

Species	Site tune	Age	Dominant canopy layer				Secondary canopy layer					
	Site type		D1	H1	G1	M1	N1	D2	H2	G2	M2	N2
Spruce	Drained	162	34.0	28.9	33	443.0	367	14.8	14.9	3	21.9	157
	Undrained	153	25.7	24.1	36	428.7	664	12.5	13.7	3	24.8	266
Pine	Drained	150	35.2	27.7	32	404.7	363	16.1	16.1	7	59.5	423
	Undrained	172	27.9	19.2	19	168.1	411	9.7	9.3	5	27.1	644

Forest stand mean values of stand parameters

Note: D1; D2 – mean diameter at breast height (cm); H1; H2 – mean tree height (m); G1;G2 – mean basal area ( $m^2 ha^{-1}$ ); M1; M2 – mean growing stock ( $m^3$ ); N1;N2 – mean tree count (trees per  $ha^{-1}$ ).

Six conus shaped litter collectors, each with a diameter of 110 cm and an area of 0.95 m<sup>2</sup>, were positioned at a height of 1.3 m above the ground along a transect in each stand. At the base of each litter collector, a litter bag was attached to accumulate all aboveground litter. Litter bag samples were collected over full calendar year with intervals of 2 weeks during the spring, summer, and autumn seasons. Winter litter was collected once in early spring and combined with spring litter. Samples were dried at a temperature of 70°C until reaching constant mass and then weighed. Carbon content of total aboveground litter was assumed as 50% of the litter dry weight mass.

#### **Results and Discussion**

Both conifer species in drained sites demonstrated generally higher litter quantities, with a concurrently higher variability in data compared to undrained sites. However, the difference between site types did not reach statistical significance (Table 2). In drained sites, pine stands exhibited higher carbon input via litter, while in undrained sites, higher litter carbon inputs were observed in spruce stands.

The estimates from northern European forests suggest an average carbon input through total tree aboveground litter of  $1.7 \pm 1.1$  t C ha<sup>-1</sup> yr<sup>-1</sup> for conifer stands (Neumann *et al.*, 2018). In contrast, local study estimated the carbon input for young to middle-aged conifer stands growing on drained organic soils to be slightly higher at  $1.82 \pm 0.02$  t C ha<sup>-1</sup> yr<sup>-1</sup> (Bārdule *et al.*, 2021). Our results indicate that old-growth forests can achieve even higher annual carbon input through aboveground litter, with mean values of  $2.80 \pm 0.29$  t ha<sup>-1</sup> yr<sup>-1</sup> and  $2.17 \pm 0.17$  t ha<sup>-1</sup> yr<sup>-1</sup> in drained and undrained sites, respectively.

Table 2

Species	Site type	Litter biomass t ha <sup>-1</sup> year <sup>-1</sup>	SE	Litter C t ha <sup>-1</sup> year <sup>-1</sup>	SE
Spruco	Drained	5.05	0.74	2.53	0.37
Spruce	Undrained	4.73	0.55	2.37	0.28
Dina	Drained	6.16	0.89	3.08	0.45
Pine	Undrained	3.95	0.35	1.98	0.28

#### Mean annual litter fall biomass and C input

Such difference in annual litter production compared to other studies could be explained with additional litter input by second layer trees (Table 1). Although it is considered that stands exceeding age of 120-130 years are rather stable in terms of annual litter production, Berg & Laskowski (2006) documented an increase in annual litter production within overmatured (>120 years) Scots pine stands over an 8-year survey period. Seasonal litterfall does not exhibit any distinct patterns 'Figure 2', unlike what was reported by Berg and Laskowski (2006), who found that 70% of Scots pine needles were shed in the autumn unless a dry summer occurred. Although in both site types, Scots pine litterfall shows the highest rates in autumn, the differences are not as pronounced. Therefore, it is possible that our study's dry summer may have influenced these results, or other factors may be affecting seasonal litterfall altogether. To better understand seasonal variation, further research spanning multiple seasons should be conducted. For spruce, it has been reported that no clear litterfall season is registered, but needles are shed throughout the year with somewhat higher rates in autumn and winter (Berg & Laskowski, 2006). Our results show that the highest seasonal rates differ between site types: for spruce in drained sites, the highest rates are observable in summer, while in undrained sites, they occur in autumn.

Local study by Butlers (2023) shows that the age has the closest relationship (R=0.8) with the total biomass of tree crown litter; however, our results do not align with this statement, showing weak negative association (R= -0.006). This suggests that old-growth forests in late successional development (age > 150 years) may exhibit distinct pattern in the relationship between stand age and litter production.

However, in our study, this assertion cannot be confirmed due to insufficient evidence, primarily stemming from the low number of stands available for such analysis.



Figure 2. Seasonal aboveground litter C stock (Whiskers denote ± 95% confidence interval).

Our results show positive moderate correlation between annual litter C input and stand characteristics such as mean tree diameter and height of dominant canopy layer (Table 3). Our results reveal a stronger correlation when the secondary canopy layer is included, as observed in the correlation with total basal area (G<sub>total</sub>) and total standing stock (M<sub>total</sub>). The strong positive correlation (R = 0.77) between total deadwood volume and litter production is noteworthy. However, establishing causation in our study is challenging due to the lack of experimental design. A simpler explanation could stem from the observation that dead standing trees, with remaining yet collapsing crowns, continue to produce litter, primarily comprising of needles, bark, and small branches. However, it is important to note that such an assertion remains theoretical. Nonetheless, deadwood could serve as an indicator of changes in site conditions that may have

affected litter production. Factors such as bark beetle (Ips typographus) infestation or strong wind disturbances could lead to both - increased litterfall and deadwood formation simultaneously (Kosunen et al., 2020). Pronounced litterfall due to changes in environmental conditions could also be explained by changes in stand structure - as more deadwood is produced, the competition for light and nutrients is reduced for remaining trees. This, in turn, could affect crown development for the secondary canopy layer litter production. Other potential and thus. relationships should not be overlooked and merit further investigation. For instance, it is plausible that lying deadwood, as it decomposes and releases nutrients, may enhance soil nutrient status, thereby influencing litter production in the secondary canopy layer (Kulka et al., 2024).

Table 3

	Age, yr	Diameter, cm	Height, m	G <sub>total</sub> , m <sup>2</sup> ha <sup>-1</sup>	M <sub>total</sub> , m <sup>3</sup> ha <sup>-1</sup>	Total deadwood, m <sup>3</sup> ha <sup>-1</sup>	Litter C, t ha <sup>-1</sup> yr <sup>-1</sup>
Age, yrs	1	0.03	-0.32	-0.37	-0.38	-0.18	-0.06
Diameter, cm	0.03	1	0.74	0.38	0.5	0.61	0.64
Height, m	-0.32	0.74	1	0.73	0.88	0.58	0.6
G <sub>total</sub> , m <sup>2</sup> ha <sup>-1</sup>	-0.37	0.38	0.73	1	0.95	0.49	0.76
M <sub>total</sub> , m <sup>3</sup> ha <sup>-1</sup>	-0.38	0.5	0.88	0.95	1	0.47	0.68
Total deadwood, m <sup>3</sup> ha <sup>-1</sup>	-0.18	0.61	0.58	0.49	0.47	1	0.77
Litter C, t ha <sup>-1</sup> yr <sup>-1</sup>	-0.06	0.64	0.6	0.76	0.68	0.77	1

Correlations matrix of stand characteristics and litter input

Our results align with other studies (Starr *et al.*, 2005; Berg & Laskowski, 2006; Bārdule *et al.*, 2021; Butlers, 2023), that basal area is the best predictor for annual litter production. Study results suggest that in old growth forest stands basal area of dominant and secondary canopy layer are significant predictors (p<0.01) (Table 4). When deadwood was included in the model, the predictive power increased, indicating its influence. The highest predictive power was observed in the model (Basal\_Dw) that included basal area of both canopy layers and total deadwood amount explaining 79% of the data variance.

Developing models with many variables can result in very accurate model predictions (Viskari *et al.*, 2022). However for practical application, a simpler model with fewer, easily measurable variables is more useful, yet with reduced precision.

Table 4

Model name	Predictors	Estimate	P value	R <sup>2</sup>	$R^2_{adj}$	Р	
Stock	M <sub>total</sub> , m <sup>3</sup> ha <sup>-1</sup>	0.003	0.016	0.46	0.40	0.016	
Basal	G <sub>total</sub> , m <sup>2</sup> ha <sup>-1</sup>	0.06	0.004	0.58	0.54	0.004	
Dw	Total deadwood, m <sup>3</sup> ha <sup>-1</sup>	0.02	0.003	0.6	0.56	0.003	
Pagal Dw	G <sub>total</sub> , m <sup>2</sup> ha <sup>-1</sup>	0.04	0.017	0.70	0.75	0.0000	
Dasal_Dw	Total deadwood, m <sup>3</sup> ha <sup>-1</sup>	0.01	0.015	0.79	0.75	0.0009	

Linear regression models for predicting annual litterfall in old-growth stands

Therefore, we constructed a linear regression model using total basal area, which explained 58% of the data variance. Two separate linear regression models were constructed to assess the relationship between total basal area and litter carbon stock for spruce and pine dominated stands 'Figure 3'. For Spruce, the model revealed a non-significant positive relationship between total basal area and litter carbon stock ( $R^2$ =0.31, p = 0.252). Conversely, for pine, the model indicated a significant positive association between total basal area and aboveground litter carbon stock ( $R^2$ =0.9, p = 0.00373). These results suggest differing relationships between species, considering speciesspecific factors in understanding litter carbon dynamics in old growth forests.



Figure 3. Annual C input by litter as a function of total basal area (± 95% confidence interval).

#### Conclusions

- 1. Drained sites exhibited higher annual litterfall C input compared to undrained sites, but differences were not statistically significant.
- 2. Seasonal litterfall did not exhibit any distinct patterns, indicating of high varialitity in late succession forest stands.
- 3. Total basal area (m<sup>2</sup> ha<sup>-1</sup>) and total deadwood volume (m<sup>3</sup> ha<sup>-1</sup>) showed a strong positive correlation with litterfall C input.
- 4. Stand basal area is the best individual predictor of annual litter C input, and provides reliable estimates

References

for practical application using easily measurable stand parameter.

5. Further studies should focus on long-term litter dynamics and sorting of litterfall by categories (needles, bark, branches, etc.) to develop more precise estimates.

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# RADIAL GROWTH RESPONSE OF JAPANESE WALNUT (*JUGLANS AILANTIFOLIA*) TO METEOROLOGICAL CONDITIONS IN LATVIA

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#### Abstract

The introduction of non-native tree species has been used as a climate change mitigation tool. To ensure the anticipated benefits, the analysis of species radial growth reactions to meteorological factors should be carried out. Initially, tree species were introduced to non-native regions as food resources, yet the focus has now shifted towards favourable wood properties and growth rates. This study used tree ring width measurements of Japanese walnut *Juglans ailantifolia* and climate data to examine the relationships between these variables. A total of 30 trees were sampled from a stand located in the southern part of Latvia. Tree ring width (TRW) was measured, and residual chronology was derived. Pearson correlation analysis was used to detect the correlating meteorological factors, and a linear mixed-effects model was used to detect the key factors. The correlation analysis indicated generally low correlation coefficients between TRW and meteorological factors, primarily correlating with summer precipitation, both the current and preceding summer, highlighting carry-over effects. Furthermore, signature years underscored the negative effect of low temperatures and summer droughts on the radial growth of Japanese walnuts. However, the observed variation in TRW between years, not fully explained by meteorological factors, suggests a dynamic rather than stable relationship.

Key words: climate, introduced trees, Japanese walnut, radial growth.

#### Introduction

The geographical distribution of plant species is affected by climate change, which is characterized by temperature increases and reduced precipitation amounts (Scheffers et al., 2016). On the one hand, climate change can bring benefits. Due to phenological shifts causing earlier budburst and delayed leaf aging in autumn, the growing season has been prolonged for about 11 days since the 1960s (Menzel & Fabian, 1999), resulting in a primary production increase. However, the anticipated positive effects can weaken as a result of elevated evapotranspiration (Lindner et al., 2014). To reduce the potential negative impact of climate change, non-native species introduction has been identified as a strategic tool. While species introduction brings a lot of gains, it also carries potential risks (Hasenauer, 2020), such as species becoming invasive, with common walnut (Juglans regia) serving as an example. Though it is widely distributed across Europe, this species demonstrates invasiveness in its secondary range (Lenda et al., 2018). Despite the potential risks, tree species that were known as food resources including almond (Prunus dulcis), apricot (Prunus armeniaca), peach (Prunus persica), sweet chestnut (Castanea sativa), and common walnut, have been introduced since ancient Greek times (Pötzelsberger et al., 2020). An important aspect of walnut cultivation in ancient times was the broad range of conditions in which they could grow (Gupta, Behl, & Panichayupakaranan, 2019). Nowadays, walnuts do not hold a significant value from an ecological perspective, yet they are economically important because of their high-quality timber, often sold at high prices. The wood of walnut has an aesthetic appeal and is easy to process; therefore, it is preferred for luxury furniture and veneer applications (Paź-Dyderska, Jagodziński, & Dyderski 2021). In some countries, Japanese walnut is cultivated for nut production, such as Belarus, Lithuania, and Ukraine (Marazzi et al., 2022). Findings reveal that the nuts from species indigenous to Japan (J. ailantifolia, J. subcordiformis) exhibit significantly higher protein and mineral content and reduced fat levels compared to conventional cultivars (Fukasawa et al., 2023). Within its native range, Japanese walnut grows in diverse mixed-riparian forests (Tamura & Hayashi, 2008). Yet even in its distribution area, the climate affects the phenological response of this species, such as flower abortion due to early spring frosts (Marazzi et al., 2022). Japanese walnut has compound leaves that can reach 90 cm in length with 11–19 hair leaflets and upright red female inflorescences that can produce up to 20 fruits (Marazzi et al., 2022). Visually distinguishing Juglans species is challenging; similar species, tigernut (Juglans mandshurica) and Japanese walnut (Roloff & Bärtels, 2018), are separate species, but molecular phylogenetic studies propose that these taxa should be regarded as a single species (Mu et al., 2017). The identification of Japanese walnut is further complicated by its potential hybridization with butternut (Juglans cinerea) (Boraks & Broders, 2014; Brennan et al., 2020). Research, primarily focused on the chemical composition of the seeds, suggests that cultivars exhibit reduced resistance to environmental factors (Fukasawa et al., 2023). Meteorological factors control the radial growth of trees, demonstrating the complex interaction between biological inheritance and environmental signals in shaping growth patterns (Matisons et al., 2019). Hence, the objective of this study was to evaluate the impact of meteorological factors on the tree ring width of Japanese walnuts in Latvia.

#### Materials and Methods

An experimental plantation of Japanese walnuts growing in Latvia, Code 'Figure 1', was chosen for

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radial increment analysis. The plantation with a size of 0.58 ha was established in the 1960s and has reached around 60 years of age (Laiviņš, 2020). Over time, a natural mixture of common ash Fraxinus excelsior and bird cherry Padus avium has occurred within the plantation. No forest management has occurred in this territory. The average temperature varied from -2.9±3.3 °C in February to +18.5±1.6 °C in July. The annual mean temperature, calculated from 1992 to 2021, was  $+7.3\pm0.7$  °C, while the mean temperature for the summer months (June-August) was 17.4±1.0 °C. Annual precipitation averaged 641±70 mm, with the summer months having the highest monthly precipitation of 72.8±29 mm. The meteorological data were sourced from CRU for grid points (Harris et al., 2020).



Figure 1. Location of the study area of Japanese walnut in Latvia. The green colour indicates territories with forest cover.

In 2020, an inventory and sample collection occurred. Tree diameter and height were measured, and Pressler's increment corer was used to extract two cores from opposing directions from each of the 30 dominant healthy trees. Following drying, the cores were mounted on wooden mounts and sanded. A LINTAB6 measuring table was used to measure treering widths (RinnTech, Heidelberg, Germany). TRW was cross-dated using COFECHA (Grissino-Mayer, 2001). Variability in the TRW series was characterized using r-bar, expressed population signal, mean sensitivity, first-order autocorrelation, and signal-tonoise ratio (Wigley et al., 1984). Principal component analysis (PCA) was used to determine radial growth patterns between selected trees. Data series were prewhitened, and residual chronology was used to determine bootstrapped Pearson correlation coefficients (Zang Biondi, 2013) with meteorological data. A linear mixed-effects model was used to detect the key meteorological factors.

#### **Results and Discussion**

Out of the 30 studied trees, successful cross-dating was done for 29 trees for the period from 1964 to 2020. The mean diameter was  $36.9 \pm 5.5$  cm, ranging from 26 to 52 cm, see 'Figure 2'. This is similar to the diameters of black walnut (*Juglans nigra*) growing in Romania, Croatia, and Germany (Nicolescu *et al.*, 2020). This suggests comparable levels of productivity. The mean height of the sampled trees was  $24.9\pm1.9$  m, ranging from 21 to 30 m, see 'Figure 3'. This is lower than for black walnut at a similar age in Italy, Croatia, and Romania (Nicolescu *et al.*, 2020) where mean height was between 24 and 30 m.



Figure 2. Measurement of the Japanese walnut with the biggest diameter.



Figure 3. Frequency of diameter (cm) and height (m) classes for the studied Japanese walnut trees.

The expressed population signal (EPS) of the sampled trees surpassed 0.85 (Wigley et al., 1984) with a value of 0.96. An intermediate (Speer, 2011) signal-to-noise ratio (SNR) and mean sensitivity (SENS) values were detected at 31.55 and 0.24, respectively. First-order autocorrelation, which describes the connection between previous and current growth was intermediate (0.36). Two principal components for tree-ring width were identified, which explained 61.4% of the total variance between trees. A homogenic response was observed, and no divergence of the growth between trees was detected; therefore, all tree-ring width (TRW) measurements were analyzed as a single group. Several signature years were detected in TRW throughout the analyzed period, see 'Figure 4A'. The highest growth rates were observed at the beginning of the development from 1964 to 1973, with an overall declining tendency indicating an age trend. The apparent decline and divergence in growth observed

around 10 years of age (1973–1977) might be linked to the onset of nut production, which happens around this age (Webber *et al.*, 2022).



Figure 4. Tree-ring width measurements (A) and residual chronology (B) for Japanese walnut. Green lines indicate individual measurements (A) and sample depth (B).

A positive signature year was detected in 1981, which was described by increased summer precipitation amounts and temperatures. Then, in 1982, a negative signature year followed. The decrease could be attributed to the latest spring frost ever recorded in Latvia (in June), given that walnuts are sensitive to spring frosts (Marazzi *et al.*, 2022). Another negative signature year was detected in 1987. This year was characterized by very low temperatures, especially at

the beginning of the year. This was followed by growth suppression from 1988 until 1998. A slight increase in growth occurred at the age of 35 (year 1999). For other walnut species (*Juglans nigra*), this period is known to be the peak phase of diameter growth (Nicolescu *et al.*, 2020). In 2003, Europe experienced an intense drought, leading to a decline in growth. Similarly, in 2006, when differences in growth patterns among trees became apparent, likely due to high temperatures in the summer.



Figure 5. Bootstrapped climate-growth relationships between tree-ring width chronologies and monthly climatic data.

Tree-ring width chronology 'Figure 4B' exhibited correlation 'Figure 5' with 10 meteorological factors, with only one having a negative correlation (SPEI before the previous June). The majority of the correlating meteorological factors were SPEI in the present and preceding summer months. Similarly, studies on other walnut species, such as English walnut (*Juglans regia*), have identified a positive correlation between radial growth and summer precipitation (Winter *et al.*, 2009). The strongest correlation was detected with SPEI before the previous June, SPEI in July, and precipitation in June, yet overall the correlation coefficients were similar and weak, ranging from 0.22 to 0.31. However, when all correlating factors were analyzed together, only two factors were evaluated as significant, including precipitation in the previous June (p = 0.032) and SPEI in the previous July (p = 0.036). This highlights the importance of summer precipitation and indicates some carry-over effects. Carry-over effects have been detected in other studies as

well (Winter *et al.*, 2009). The marginal R values (R2m) indicated that meteorological factors account for 11% of the TRW variance. When considering conditional R (R2c), which incorporates other factors, 52% of the

#### Conclusions

- 1. The main meteorological factors affecting Japanese walnut growth in Latvia are precipitation in the previous and current summers.
- 2. Signature years highlight the negative effect of low temperatures and summer droughts on the growth of Japanese walnuts.
- 3. A significant variation in TRW between years was

variance was explained. This indicates a larger variation between years rather than among individual trees, with meteorological factors not being the main drivers of this variation.

evident and was not explained by meteorological factors alone, suggesting a non-stationary relationship.

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# RESPONSES OF HYBRID ASPEN *IN VITRO* CULTURES TO DIFFERENT PROPORTIONS OF RED AND BLUE LIGHT

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#### Abstract

Light is one of the most significant environmental factors affecting the growth of plants, as it is the driving force of photosynthesis. Among others, the red and blue light are the most relevant, as these spectral regions are absorbed by chlorophyll the most. In addition, red and blue light trigger specific photomorphogenic responses that allow plants to capture the available light efficiently. Accordingly, the proportion of red and blue light (R:B ratio) is considered one of the most important characteristics of light for plants, as optimal R:B provides balanced growth and photosynthesis. The aim of this study was to evaluate how the *in vitro* cultures of hybrid aspen (*Populus tremula* L.  $\times P$ . *tremuloides* Michx.) are affected by different R:B ratios under fixed illumination intensity. We examined the growth characteristics of plantlets under wide spectrum LED luminaires with three different R:B proportions – 1:1, 7:3 and 9:1. While photosynthesis-related variables were significantly affected by light, the effect on morphology was less pronounced. Overall, increased proportions of red light decreased the photosynthetic performance of plantlets without giving significant benefits in the form of longer shoots that could be used to facilitate propagation effectiveness. Nonetheless, the effect of light treatment remains at least partially clones-specific and should be considered in case of further application for propagation purposes.

Keywords: LED, Populus tremula x P. tremuloides, photosynthesis, photomorphogenesis, R:B ratio.

#### Introduction

As demand for wood-related products continues to increase, the use of highly productive and stress tolerant genotypes of forest tree species becomes more relevant (Konnert et al., 2015). In the Eastern Baltic region, hybrid aspen (Populus tremula L. × P. tremuloides Michx.) is a promising option, as it exhibits superior growth compared to local tree species and can be used for wide range of applications (Niemczyk et al., 2019). The superiority of hybrid aspen derives from the phenomenon of heterosis (or hybrid vigour), where offspring exhibits traits that exceed those of parent species, resulting in faster growth, higher productivity, and resilience to stress factors (Li, Howe, & Wu, 1998; Hu & Thomas, 2019). Characteristics of heterosis are expressed in  $F_1$ generation, accordingly reproductive material of hybrid aspen clones needs to be propagated vegetatively (Stanton, Neale, & Li, 2010). For this, propagation by micro shoot cultures in vitro is the most relevant technique, as it provides higher productivity compared to conventional vegetative propagation methods (Winton, 1971).

Light is one of the most significant environmental factors affecting plant growth both *in vitro* and *ex vitro*, as it is used as the primary energy source for photosynthesis (Wang *et al.*, 2022). Red and blue spectral regions are the main driving force of photosynthesis, as these photons are absorbed by chlorophyll the most (Lichtenthaler, 1987). Accordingly, plants have developed photoreceptors allowing them to detect light conditions and adjust their architecture to capture the available light efficiently (Wang *et al.*, 2022).

Red light is absorbed by phytochromes and is associated with increased shoot elongation, accumulation of starch (Muleo & Thomas, 1997;

Werbrouck et al., 2012; Chen et al., 2018; Fan, Manivannan, & Wei, 2022), and is used for photosynthesis more efficiently than blue light (Fan et al., 2013). Blue light is absorbed by cryptochromes and is associated with chlorophyll synthesis (Hung et al., 2016; Chen et al., 2018) as well as chloroplast movement and stomatal size and opening (Hogewoning et al., 2010; Fan et al., 2013; Chen et al., 2018; Moosavi-Nezhad et al., 2021), all of which significantly contribute to photosynthetic capacity. Therefore, a balanced spectrum is a prerequisite as a means to provide efficient photochemical reactions and morphogenesis. Furthermore, plants have evolved to perceive the wide spectrum of sunlight; accordingly, the effect of monochromatic illumination can be misleading (Kondratovičs et al., 2022) and the light signal should be interpreted as an interaction of several wavelengths simultaneously (Hogewoning et al., 2010; Wang et al., 2022).

The ratio of red and blue light (R:B) is considered one of the most important characteristics of light due to its significance in photosynthesis (Fan, Manivannan, & Wei, 2022). A balanced distribution between both wavelengths ensures optimal development of plants; however, it depends highly on the ecology of species and has been intensely studied in various crops (Piovene et al., 2015; Naznin et al., 2016a; Naznin et al., 2016b; Chen et al., 2018). As regards the effects of R:B ratio, trees, which are long living organisms have been little studied. The aim of this study was to evaluate how the *in vitro* cultures of hybrid aspen are affected by different R:B ratios under fixed illumination intensity. We hypothesize, that hybrid aspen clones will exhibit higher plasticity in terms of morphological changes due to more plastic adaptation mechanisms utilized by trees.
## **Materials and Methods**

This research was carried out in the Laboratory of Plant Physiology of Latvian State Forest Research Institute 'Silava' in the summer season of 2023. The plant material used in this study was already established micro shoot cultures of locally bred hybrid aspen clones named No. 28 and No. 90 with intermediate field productivity (Zeps et al., 2022). Prior to the experiment, the stock material was maintained by routinely transplanting every 4 weeks on fresh 1/2 concentration Murashige & Skoog (MS) medium (Murashige & Skoog, 1962), supplemented with 0.1 mg  $L^{-1}$  indole-3-butiric acid (IBA), 20g  $L^{-1}$ sucrose and solidified with 6g L<sup>-1</sup> plant agar (Sigma-Aldrich, USA). Prepared culture medium was poured into 300 mL glass jars (approximately 30 mL per jar), covered with aluminium foil and sterilized in an autoclave for 15 min at 121°C under 110 kPa of pressure. The pH of the culture medium was adjusted to 5.8 prior to autoclaving. For the experiment, fully

regenerated hybrid aspen micro shoots were excised into approximately 1.5 cm long explants and transferred to culture vessels (8 explants per each vessel) containing the same medium as mentioned above.

To evaluate the effects of R:B ratio on hybrid aspen clones, *in vitro* cultures were cultivated in growth chamber on shelf systems equipped with full-spectrum LED luminaires with three different R:B ratios – 9:1; 7:3 and 1:1 (Table 1). The total photon flux (wavelength range 400-750 nm) on shelf surface of all treatments was set to  $70\pm7 \ \mu mol \ m^{-2} \ s^{-1}$ . Measurement of spectral composition and photon flux were carried out using AvaSpec ULS2048 spectrometer (Avantes, The Netherlands) to ensure the uniformity of illumination. Environmental conditions in the growth chamber were maintained constant during the experiment – temperature in growth chamber was set to 25°C, relative humidity at 30-40% and photoperiod to 16/8h (day/night).

Table 1

Spectral distribution of studied light treatments (% of total photon flux in the range of photosynthetically active radiation)

Spectral regions and ratios	50% Red, 50% Blue (1:1)	70% Red, 30% Blue (7:3)	90% Red, 10% Blue (9:1)		
Blue 400-500 nm	35.0	21.4	7.1		
Green 500-570 nm	12.7	13.1	12.4		
Yellow 570-590 nm	2.7	2.8	2.6		
Orange 590-625 nm	7.0	7.4	7.2		
Red 625-700 nm	35.5	52.9	62.0		
Far-red 700-750 nm	1.8	1.8	1.7		
Red:Blue (R:B)	1.01	2.47	8.75		

After 4 weeks of cultivation in above mentioned conditions, we determined the morphological and physiological characteristics of regenerated plantlets. Stem and internodal length was measured with a caliper, and the number of internodes was determined. Leaf morphology-related parameters were determined by analysing scanned images of leaves. Newly formed leaves of each plantlet without petioles were placed on a tablet in order from youngest to oldest, covered with transparent glass and scanned with Canon LC4800P scanner (Canon Inc., Japan). The obtained highresolution  $(1275 \times 1752 \text{ px})$  grayscale images were then processed with WinFolia Pro 2019 software (Regent Instruments Inc., Canada). Minor deformations such as cracks and overlaps were graphically corrected with the software to increase the accuracy of measurements. Further analysis was conducted on edited images - the average and total leaf area as well as the number of leaves of each plant were determined.

In parallel to morphological measurements, the physiological parameters of the same plants were measured. Relative chlorophyll concentration (SPAD) was measured for each newly formed leaf (expressed as a mean value of 5 measurements for each leaf), while data representation occurred on a plant scale (each SPAD value is the mean value of all one plant's leaves). Chlorophyll a fluorescence, as an indicator of photosynthetic efficiency was measured with HandyPea (Hansatech Instruments Ltd., UK). 4th leaf from the top of each plantlet was used to represent the fluorescence of entire plant. Leaves were detached from plant and dark-acclimated in a special clip for 15 min, in order to open all excited reaction centres of photosystems. Measurements were carried out on dark-acclimated leaves by exposing to short (1s) and saturated (1500  $\mu$ mol m<sup>2</sup> s<sup>-1</sup>) pulse of red light and measuring reemitted fluorescent light. Initial assessment of data was carried out in PEA PLUS v.1.13 (Hansatech Instruments Ltd., UK) - fluorescence parameters were evaluated and exported as data points for analysis. To describe the functionality of photosynthetic apparatus, performance parameters Area, Fv/Fm, PIABS, and PITOTAL as well as special energy fluxes ABS/RC, DIo/RC, TRo/RC, ETo/RC and describing absorption, dissipation, trapping, and electron transport rates, respectively, were further analysed.

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The effects of R:B treatment and clone and interaction of factors were assessed using Two-way ANOVA. For the variables that exhibited the highest significant effect of light treatment or light by clone interaction based on F-values, the estimated marginal means were compared with Tukey's HSD test. Data analysis was performed with Microsoft Excel 2019. Altogether, data from 314 plants was acquired (3 light treatments on 2 clones each).

# **Results and Discussion**

*In vitro* cultures of hybrid aspen exhibited sensitivity to the different R:B ratios, as indicated by a significant effect of light treatment on studied variables. However, the effects were uneven as different R:B ratios primarily affected the physiology of plantlets: functionality and effectiveness of PS II (indicated by TRo/RC and ABS/RC), as well as the overall performance of photosynthetic apparatus (Area, PI<sub>ABS</sub> and PI<sub>TOTAL</sub>) (Table 2). The relative chlorophyll content (SPAD) was also significantly affected by different R:B ratios; however, the effect of light treatment for this variable was clone-specific (Table 2), indicating different adaptation mechanisms of photosynthetic capacity of clones. The effect of light treatment on morphology was less pronounced, as only the number of internodes (which was also clonespecific) and number of leaves, were significantly affected by light treatment.

Table 2

Fyaluation of the significance of fixed	l affacts and interaction on	n variables (represented as F_valu	DC)
Evaluation of the significance of fixed	ו כווכנוס מווע ווונכו מנווטוו טוו	i variables (representeu as r-varu	

Variables	Clone	Light	Interaction of factors	
Mean leaf area	1.497	1.176	1.728	
Summary leaf area	8.393**	0.934	2.067	
Number of leaves	17.162***	3.601*	0.634	
Main shoot length	0.501	1.424	0.18	
Number of internodes	46.72***	1.36	5.73**	
Area	49.349***	5.890**	2.407	
ABS/RC	105.300***	3.821*	1.205	
DIo/RC	86.927***	2.287	0.955	
TRo/RC	100.944***	7.465***	1.266	
ETo/RC	15.898***	0.294	0.515	
PI <sub>TOTAL</sub>	110.447***	4.885**	0.991	
PI <sub>ABS</sub>	215.76***	9.16***	0.29	
Relative chlorophyll content	30.53***	18.14***	4.81**	

\*, \*\*, and \*\*\* represent the levels of significance at p-values 0.05; 0.01 and 0.001, respectively. ABS/RC, DIo/RC, TRo/RC, ETo/RC are specific energy fluxes in photosystems – absorption per reaction centre, dissipation per reaction centre, trapping rate per reaction centre and excitation transfer per reaction centre, respectively, while PI<sub>TOTAL</sub> and PI<sub>ABS</sub> represent performance of overall photosynthesis and light absorption, respectively.

When exposed to new environmental conditions, the sensory system of plants induces changes and first adjustments occur on a molecular and then on a physiological level, affecting respiratory rate, photosynthesis, stomatal opening, and other processes (Chelli-Chaabouni, 2014). Changes in morphology are more robust in this matter. Morphological traits have been reported to exhibit carry-over (or legacy) effects, meaning that current structures are the result of environmental conditions (light included) to which plants were exposed before the changes (Jiang et al., 2011; Trouwborst et al., 2016), and have been considered in the context of propagation process of hybrid aspen (Zeps et al., 2022). Accordingly, it can be assumed that to overcome these legacy effects, significant and therefore presumably stressful stimulus is required. However, light treatment in this study did not affect maximum quantum yield (Fv/Fm) (Table 2), which is used as a sensitive indicator of the efficiency of light absorption (Maxwell & Johnson, 2000; Moosavi-Nezhad et al., 2021), indicating that the treatment did not cause significant stress.

Furthermore, in crop and herb species, changes of R:B usually result in adjustments of leaf size, length of stem, and other morphological structures (Hahn, Kozai, & Paek, 2000; Piovene et al., 2015; Naznin et al., 2016a; Naznin et al., 2016b). However, from the perspective of ecology, perennial tree species have long-lasting biological cycles and, accordingly, have developed more plastic growth strategies than annuals or biannuals in order to endure potentially stressful environment for longer periods of time (Chelli-Chaabouni, 2014). One of such strategies would include adaptation to a wider range of conditions and therefore higher phenotypic plasticity and lower sensitivity to changing environmental conditions. In the case of hybrid aspen, this is further enhanced by the effect of heterosis, where clones exhibit higher plasticity to environmental conditions compared to parent species (Li, Howe, & Wu, 1998; Hu & Thomas, 2019). Such plasticity to illumination was also linked to field performance with more productive clones being less sensitive (Kondratovičs et al., 2022). Clones, used in this study were with intermediate field productivity. Accordingly, it can be assumed that the selected light treatment was not a strong enough stimulus to cause changes in morphology due to higher plasticity characteristic to tree species and further enhanced by the effect of heterosis.

Clones adjusted to changed R:B ratios primarily via adjustments of photosynthetic apparatus. Although similar relative chlorophyll concentrations (SPAD) were observed for both clones under R:B ratios 1:1 and 7:3, values of the variable of clone No.28 cultivated under 9:1 were significantly lower, indicating on negative effect of elevated amount of red light 'Figure 1A'. Additionally, with an increasing proportion of red light the efficiency of photosynthetic apparatus and overall vitality of plantlets, represented by PI<sub>ABS</sub>, dropped, as indicated by a gradual linear decrease 'Figure 1B'. At the same time, specific energy fluxes, represented by TRo/RC, increased with the proportion of red light 'Figure 1C', indicating elevated energy distribution and utilization rates within the photosynthetic apparatus.



Figure 1. Responses of relative chlorophyll content (A), PI<sub>ABS</sub> (B), energy trapping rate (C) and number of internodes (D) to different R:B ratios in illumination.

Increasing proportion of red light also resulted in a decrease of the number of internodes, as indicated by significant differences between 7:3 and 9:1 'Figure 1D'. However, the decrease was not linear, as the number of internodes for 9:1 was similar to those of 1:1, indicating a complex mechanism of regulation. Although red light is actively used for photosynthesis, it has been recorded to inhibit photosynthesis. In cucumber, monochromatic red light has been observed to cause partially reversible damage to photosynthetic systems (so-called 'red syndrome') (Trouwborst *et al.*, 2016). At the same time, increasing blue light to at

least 7% of total photon flux, seemed to be sufficient to overcome 'red syndrome' and increase photosynthetic capacity two times and continued to increase it until up to 50% of total photon flux was reached (Hogewoning et al., 2010). Similarly, the application of blue light was reported to promote photosynthesis by chlorophyll increasing concentrations of in vitro cultures of potato and highbush blueberry (Hung et al., 2016; Chen et al., 2018), as well as the efficiency of the photosynthetic apparatus of watermelon seedlings ex vitro (Moosavi-Nezhad et al., 2021) and mung bean (Kumar et al.,

2020). Blue light has also been reported to increase the number of internodes in *Prunus cerasifera* cultures *in vitro* (Muleo & Thomas, 1997). This, however, does not fully explain why significant differences between 9:1 and 1:1 R:B ratios were not detected. Accordingly, it can be assumed that the lack of differences could have resulted from marginal values of dispersion, as the effect of light treatment, indicated by the F-value, is relatively low (Table 2).

Although red light seemed to increase specific energy flux rates, in many cases this is considered either a photoprotective or compensatory mechanism. In excessive illumination, usually more light is absorbed and trapped, leading to increased ABS/RC and TRo/RC values (Moosavi-Nezhad et al., 2021). However, to protect photosystems, a proportionally higher amount of energy is dissipated as heat, accordingly increasing DIo/RC flux at the same time. On the contrary, in limited light conditions, electron transport within photosystems occurs more efficiently, leading to increased ETo/RC values (Maxwell & Johnson, 2000; Kumar et al., 2020). Accordingly, the specific photon fluxes need to be examined in the context of overall photosynthetic performance. Increased TRo/RC values, in this case, were most likely a compensatory mechanism to provide stable energy flow for photosynthesis under decreased efficiency as indicated by decreasing performance index (figure 1B). Similar increases of TRo/RC as a response to elevated amounts of red light have been observed in mung bean and grafted watermelon seedlings (Kumar et al., 2020; Moosavi-Nezhad et al., 2021). In these studies, however, red light also caused changes in Fv/Fm value, which was not true in our study, further emphasizing the lower susceptibility of trees to stress caused by illumination changes.

Nonetheless, conditions *in vitro* differ significantly from those *ex vitro*, and the observed responses are a result of interaction between several independent factors, such as the composition of the culture medium. For example, due to reduced gas exchange between the culture vessel and the surrounding environment, the photosynthetic rate of *in vitro* cultures remains questionable (Hahn, Kozai, & Paek, 2000). Furthermore, both phytochromes and cryptochromes interact with auxins and cytokinins, respectively (Wang *et al.*, 2022), and there is still a lack of information concerning the magnitude of these factors.

# Conclusions

- 1. We conclude that physiological responses of hybrid aspen *in vitro* culture to changes in R:B ratio are more versatile than changes in morphology. Accordingly, plants adjust to changing light conditions first with adjustments in physiology.
- 2. Elevated proportions of red light are unsuitable for the propagation of hybrid aspen clones, as they decrease the photosynthetic performance of plantlets without giving significant benefits in the form of longer shoots that could be used to facilitate propagation effectiveness.
- 3. Nonetheless, the effect of light treatment remains at least partially clones-specific, thus requiring additional consideration in case of further application for propagation purposes.

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# THE COMPOSITION AND RICHNESS OF GROUND COVER VEGETATION IN DRAINED FOREST STANDS

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# Abstract

Forest drainage is a common management practice, carried out in order to improve tree growth; however, the alterations in hydrological and microclimate dynamics can cause diverse changes in the characteristics of ground cover vegetation. The aim of study was to characterise the composition and richness of ground cover vegetation in drained forest stands, where the groundwater levels have been affected by the reconstruction of drainage diches. Research was conducted in the hemiboreal forests of Latvia. Three study sites were chosen, measurements of groundwater level, stand parameters and projective cover of ground covered vegetation took place in two stands which underwent reconstruction and restoration of the drainage system in 2019, and a control stand, where the drainage system had not been restored. For assessing the relationship of ground cover vegetation in relation to groundwater level and stand factors, DCA analysis was used. The differences between stands, regarding the species projective cover and species composition, were assessed by ANOSIM (Analysis of similarities). Sites, where drainage ditches were fully or partially reconstructed exhibited a greater diversity of ground cover vegetation species compared to the control stand, where no renewal of drainage ditches had occurred. Conversely, the control stand displayed a higher projective cover of the bryophyte layer. The composition of ground cover vegetation species differed amongst all studied stands, the varying stand characteristics and co-dominant tree species in canopy layer had a more pronounced influence on ground cover vegetation, making it complicated to evaluate direct impact of groundwater level.

Key words: ground cover vegetation, projective cover, drained forests, organic soils.

# Introduction

Forest drainage has been practiced for over 250 years, with discussions on its impact on tree growth dating back to the middle of the 20<sup>th</sup> century (Heikurainen, 1964). By creating drainage ditches and lowering the groundwater table, soil aeration enhances, hence promoting improved tree growth and CO<sub>2</sub> removal for atmosphere (Lõhmus, Remm, & Rannap, 2015). Despite the regionally contradictory results, regarding greenhouse gas emissions (GHG), caused by drainage of organic soils (Tiemeyer et al., 2020; Lazdiņš et al., 2024), no significant changes in carbon (C) stock have been observed in the Baltics (Dubra et al., 2023). However, anthropogenic disturbances usually have a heterogeneous and complex effect on ecosystems; consequentially, in the context of drainage, variable hydrological and shading conditions are initiated. The implementation of drainage ditches tends to have an uneven influence on water table; drainage redirects water flow and develops a systematic pattern, where water levels decline as the distance from the ditch increases (Haapalehto et al., 2014). Additionally, changes in groundwater level can alter proximate surroundings of the stand, including microclimate and composition of ground cover vegetation (Chipman & Johnson, 2002; Paal et al., 2016; Sikström & Hökkä, 2016).

Forest ground cover vegetation and its diversity is an essential component of forest ecosystems, functioning as nutrient supply, along with serving as an irreplaceable habitat and shelter for various life forms (Felton *et al.*, 2017; Felton *et al.*, 2018; Zhang *et al.*, 2018; Vélez, Martínez-Peña, & Castrillo, 2023). Furthermore, ground cover vegetation ensures improved growth conditions by balancing soil moisture and regulating soil fertility (Nilsson & Wardle, 2005; Petersson *et al.*, 2019; Teixeira *et al.*, 2020). The composition of understory vegetation is

mainly defined by the prevailing tree species and soil type. The dominant tree species determine light intensity variation throughout growing season and the chemical composition of forest floor's organic debris (Sorenson *et al.*, 2011; Petersson *et al.*, 2019). Furthermore, changes in geogenic factors - nutrient availability and moisture (Chipman & Johnson, 2002), can alter the cover, abundance and diversity of individual vegetation species.

Biodiversity responses to forest drainage are multiplex and result from various interacting changes in abiotic and biotic conditions. The changes in ground cover vegetation within human-influenced landscapes are impacted by activities in the surrounding catchments, yet local disturbance history appears to have a greater influence than the broader regional context (Pellerin et al., 2016). The abundance of different bryophyte and lichen species are known to be affected by drainage (Remm et al., 2013). The species colonizing drained sites are often viewed as typical post-disturbance, successional, and adaptable - common in managed forest landscapes (Remm et al., 2013). To thoroughly understand the influence of forest drainage on the forest ecosystem within the study area and to compile a comprehensive overview of background information, evaluation of the understory vegetation is substantial. The aim of study was to characterise the composition and richness of ground cover vegetation in drained forest stands, where the groundwater levels have been affected by the reconstruction of drainage diches.

## **Materials and Methods**

## Description of the study area

This research was conducted in hemiboreal forests situated in the central region of Latvia (N 56° 42`; E 26 50`, EPSG: 4661) within the Veseta River catchment area, see 'Figure 1A'. The predominant tree

species in this area are *Pinus sylvestris L*. and *Picea abies* ((L.) H. Karst.). Initially, the study area, characterized by organic soils (Fibric histosols), was a transitional mire within the hemiboreal vegetation zone. In 1963, a forest research station was established, the current study area was defined as *Myrtillosa turf. mel*, representing poorly acidic peat soil formed by the drainage of transitional bog. Data collection took place in three forest stands, two of

which underwent reconstruction and restoration of the drainage system in 2019 e.g. 'FR' (fully reconstructed) site, see 'Figure 1D', where reconstruction of two adjacent diches was carried out, and 'PR' (partially reconstructed) site, see 'Figure 1C', where only one of the adjacent drainage diches was restored. Lastly, a control site was chosen – 'LE' (Long-established), see 'Figure 1B', where the drainage system had not been restored.



Figure 1. The location of study sites.

## Data sampling

Three circular sampling plots with an area of  $500 \text{ m}^2$  were establish in each of chosen forest stands, see 'Figure 1'; nine plots were established in total. The placement of the sample plots was arranged in a row, perpendicular to the restored ditches – so that the nearest and furthest area from the dich was characterized 'Figure 1, B, C, D'. In the case of control site, the plots are located perpendicular to the long-established ditches. Within each sampling plot, the dimensions of all trees, with diameter at breast height (DBH) greater than 6 cm, were measured.

In all plots of FR and PR sites a groundwater level measurement tool Rugged TROLL 200 Data Logger (In-Situ, Inc.) was installed (except one plot (PR1) in partially reconstructed forest stand). For the installation of the data logger, a two-meter-long plastic pipe was dug in each sample plot, in which a water level measuring device was placed. Holes were drilled in the lower part of the tube to ensure the flow of water. To ensure that the pipe would not fill up with the inflowing soil, the lower outer part of the pipe was stetd with a geotextile. Each deployed data logger was set to collect groundwater elevation readings at one-hour intervals. Additionally, since the elevation and distance between the sites is relatively small, one Rugged BaroTroll 200 data logger (In-Situ, Inc.) was positioned at the land surface to monitor and record barometric pressure for all three sites. In the LE (control) site, the water level measurements were carried out manually.

In each sampling plot, the relative projective cover of ground flora was determined in 12 grid plots of size of  $1 \times 1$  m, arranged systematically to the four cardinal directions whit a spacing of 1 m between the grid plots, see 'Figure 2'.



Figure 2. The scheme of study plot structure; tree stand measurement area and ground cover vegetation surveying grid.

The ground cover vegetation was divided and described within three layers: herbaceous vascular plants, woody plants (at an herbaceous layer) and bryophytes. The relative projective cover was assessed for all species individually; the total cover was allowed to exceed 100%, however, this restriction applied within the distinguished ground cover vegetation groups. The projective cover of bare soil, litter and wood debris was also determined. The ground cover vegetation survey, as well as the depth to groundwater measurements took place in 2021, in June-August and May-August time periods, respectively. The measurements of tree parameters took place in 2023; however, no chances in the structure or growth conditions had been detected.

#### Data analysis

The characteristics of forest stand for each plot were assessed by calculating basal area, standing stock and density of the canopy layer. Mean values for DBH and height (H) within each plot were obtained. To specify the composition of canopy layer, the proportion of each of the tree species was assessed.

In order to decribe the range of water level variation in studied forest sites, two time periods were distinguished, see 'Figure 3'. Measurements from May and June were combined as the measurements of the 'Spring' season. The measurements from July and August were assigned to 'Summer' season.

In order to describe the range of the possible water level variation, the minimal and the maximal depth to the groundwater was assessed in all study plots for both time periods. For the obtained results to be more uniform, data collected from the automatically obtained measurements were selected on the days when manual water level measurements were performed.

To gain an understanding of the composition and richness of the ground cover vegetation, the mean projective cover was obtained for vascular, woody and bryophyte layers separately. Furthermore, the mean projective cover of bare soil, litter and dead wood was assessed. For evaluating the communities of ground cover vegetation and the primary ecological gradients, DCA (Detrended Correspondence analysis) (Hill & Gauch, 1980) was utilized. The mean projective cover of the vegetation of grid plots was used as the basis for the analysis, and the downweighing of rare species was performed. For assessing the relationship of ground cover vegetation and stand factors, a matrix, containing information about the minimal and maximal depth to groundwater and taxation indices was used in DCA analysis and the variables were displayed as vectors. To find out whether there are differences between stands regarding the species projective cover and species composition, the ANOSIM (Analysis of similarities) (Clarke & Green, 1988), using Bray's distance, was calculated. To improve the comprehensibility and visualisation of ANOSIM results, boxplot graph was created. The statistical analysis was performed, using R software (R Core Team, 2023) and package 'vegan' (Oksanen et al., 2022).



Figure 3. Comparison of the minimal and maximal depth to the groundwater level in studied stands depending on the drainage system status: LE – Long-established (control); FR – Fully reconstructed; PR – Partially reconstructed. 'Spring' period includes measurements from May to June, 'Summer' period – from July to August.

#### **Results and Discussion**

The studied PR and FR stands had rather similar mean stand volume, 107.6 and 105.8  $m^3ha^{-1}$ , respectively; the LE (control) site had a higher mean stand volume – 275.4  $m^3ha^{-1}$ . However, the FR stand was approximately twice as dense as the rest, with a mean of 1027 canopy trees ha<sup>-1</sup>, while the PR stand had 640 and the LE (control) stand – 447 canopy trees ha<sup>-1</sup>. The

individual tree dimensions were more similar in the PR and FR stands, the mean DBH being 16.6 cm and 14.0 cm, and the mean tree height being 15.4 m and 13.4 m, respectively. The LE (control) site had trees of larger dimensions; the mean DBH reached 26.9 cm and the mean height of canopy trees – 23.6 m. In all three sites the canopy was dominated by *Picea abies* – 90 %, 70 % and 60 % of canopy trees in PR, FR and LE (control)

site, respectively. All three study sites had an admixture of *Betula pendula*, for the PR stand a mean of 10 %, for the FR stand a mean of 30 %, but for the LE (control) stand < 10% from all canopy trees. Additionally, the LE (control) stand had an admixture of *Pinus sylvestris*, that reached a mean of 40% of all canopy layer trees.

The range of groundwater level differed among the studied forest stands 'Figure 3'; in case of all of the research sites, the lowest depth to groundwater was detected in spring season, reaching (mean  $\pm$  standard deviation) 26.7  $\pm$  10.1 cm, 37.5  $\pm$  24.1 cm and 52.6  $\pm$ 30.5 cm on average in LE, PR and FR sites, respectively. The maximal depth to groundwater in spring season was more diverse amongst the research stands; the least amount of variation between the minimal and maximal depth to groundwater was observed in the LE (control) site, where the maximal depth to groundwater level reached a mean of 45.0  $\pm$ 12.2 cm. For the summer season, the lowest depth to groundwater was  $46.9 \pm 24.9$  %,  $53.3 \pm 9.1$  % and 64.6 $\pm$  34.3 % in the PR, LE (control) and FR stands, respectively. In case of all of the studied plots, the greatest depth to groundwater was observed in the summer season, reaching a mean of  $70.3 \pm 8.5$  %, 96.6  $\pm$  19.5 % and 112.1  $\pm$  13.3 % in the LE (control), PR and FR site, respectively. Overall, the greatest differences in the range of the depth to groundwater were detected in FR and PR stands, where the reconstruction of drainage diches, to some extent, took place in 2019, see 'Figure 3'.

A total of 73 different ground cover vegetation species were detected in research sites of which 48, 10 and 16 were of vascular, woody and bryophyte layer, respectively. The highest number of species was found in PR stands -47different species, of which 26 were vascular plant, seven were woody plant and 12 bryophyte species. Similarly, all together 41 different species were found in FR forest stand; the recording contained 30 vascular, four woody and seven bryophyte species. The lowest number of species was detected in the LE (control) stand, summing up to 33 different ground cover species of which 18, seven and eight were vascular, woody and bryophyte species, respectively. The mean projective cover of vascular plants in FR stand was 27.7  $\pm$  7.7 %, in LE stand – 56.5  $\pm$  7.9 % and in PR stand  $-57.2 \pm 15.3$  %. The highest mean projective cover of woody plant species was recorded in PR stand ( $25.8 \pm 13.3$  %), followed by the LE stand  $(11.2 \pm 5.7 \%)$  and the FR stand  $(4.7 \pm 4.4 \%)$ . The mean projective cover of bryophyte species in the FR stand was  $49.9 \pm 15.5$  %, in the PR stand  $-46.7 \pm 12.7$ % and in the LE stand  $-63.3 \pm 7.7$  %.

Little to no projective cover of bare soil was detected in the research sites; however, the highest mean projective cover of bare soil was found in the FR stand  $-0.8 \pm 1.4$  %. The highest mean projective cover of tree stand litter was recorded in the FR stand or 52.5 ± 12.8 %, followed by the LE and the PR stand, which had 24.4 ± 4.1 % and 17.9 ± 14.2 %, respectively. The mean projective cover of wood debris was highest in the LE stands  $-1.0 \pm 0.6$  % and lowest in the FR stand  $-0.8 \pm 1.4$  %.

As a result of the DCA analysis, two-dimensional graphs for both species and sampling sites were obtained, see 'Figure 4'. The eigenvalues were 0.588 and 0.248 for the first and the second axis, respectively. No overlapping of studied sample plots was detected, indicating that the species composition and stand characteristics were heterogeneous.



Figure 4. The image of the detrended correspondence analysis (DCA) of forest ground level vegetation species (A) and sample plots (B) according to their projective cover in forest stands where the drainage system has

cover in forest stands where the drainage system has either been long-established (control), partially reconstructed or fully reconstructed. Species acronyms containing 8 letters (first 4 from the first and first 4 from the second scientific name) were used. Abbreviations of vector names: P – proportion of pine in canopy; E –

proportion of spruce in canopy; B – proportion of birch in canopy; tree\_D – mean diameter of canopy trees; M, m<sup>3</sup>ha<sup>-1</sup> – mean total stock of canopy tree per ha; N, ha<sup>-1</sup> – mean number of trees per ha; gw\_Sp\_min – the minimal depth to groundwater in May-June period, cm;

gw\_Su\_min - the minimal depth to groundwater in July-August period ; gw\_Su\_max - the maximal depth to groundwater in July-August period.

The proportion of *Picea abies* in canopy layer was positively corelated with the first axis, suggesting that the first axis reflected a gradient of either light availability or spruce needle induced acidity (or combination of both), as it has been revealed in findings of previous studies (Saetre *et al.*, 1997). Increased proportion of spruce was more characteristic to the PR plots; species associated with rather high soil moisture content, for example, *Galium Aparine*, Urtica Dioica, Poa Palustris, Filipendula Ulmaria, Paris Quadrifolia, Geum Rivale, Veronica chamaedry, Climacium Dendroides, Angelica Sylvestris, were more common in the mentioned plots.

The minimal depth to groundwater in summer season also had a positive correlation with first axis gradient; however, the influence was slight. The second axis was positively correlated with such factors as stand density, the proportion of Betula pendula in canopy layer and projective cover of tree litter. Nonetheless, the second gradient was approximately half as long as the one describing the X axis, making it difficult and discouraging to draw conclusions. However, previous research has found, that the deciduous leaf litter is less acidic (Saetre et al., 1997). Moreover, studies have shown that it influences the moisture of surface soil layer, advancing the growth of vascular plants and underscoring the beneficial effect of deciduous species in coniferous stands (Esteso-Martínez & Gil-Pelegrín, 2004). The scores of LE (control) plots had a slight positive correlation with the projective cover of bare soil and higher minimal depth to groundwater level. Such species as Trientalis Europaea, Rubus Saxatilis, Dicranum Solidago Polysetum, Virgaurea, Chamaenerion Angustifolium, Circaea Alpina, Sorbus **D**ryopteris *Carthusiana*, Aucuparia, Hylocomium Splendens, Ptilium Crista-castrensis, are common in various types of forest and were more associated with these plots.

In order to assess the similarity of species composition in the selected stands, ANOSIM analysis was applied. Dissimilarity rank within each group of plots was relatively low 'Figure 5', suggesting that the species composition and projective cover were similar within studied plots for each site group. However, the species composition varied significantly amongst study sites, as indicated by the dissimilarity R value and p value (R=0.9, p = 0.003).

The high dissimilarity of composition of ground cover vegetation in the FR, PR and LE (control) stands is likely due to distinct stand structural (stand volume, density, canopy tree species) differences, which, in recent studies, have been described as an important aspect, affecting the ground cover vegetation (Remm *et al.*, 2013; Matisone *et al.*, 2023), making it hard to evaluate the impact of groundwater level on species composition and richness.

Consequentially, the admixture of canopy tree species (Sorenson *et al.*, 2011; Petersson *et al.*, 2019) and the local stand factors, as well as the history of study sites (Pellerin *et al.*, 2016) are known to have a crucial influence on composition of ground cover vegetation. However, identifying suitable research locations presents a significant challenge, this has also been pointed out by other researchers (Remm *et al.*, 2013).



Figure 5. Boxplot illustrating the ANOSIM Dissimilarity Rank based on mean projective cover of ground cover vegetation across different site types, where the drainage system has either been longestablished (LE, control) or partially reconstructed (PR), or fully reconstructed (FR). The plot displays the distribution of ranks alongside corresponding statistical values – R statistic and p-value.

Assessing the potential for possible changes of ground cover vegetation in our studied stands is important, especially for the effective planning and management of drained forests (Čakšs *et al.*, 2018). The assessment of long-term impact of groundwater level on vegetation growing on organic soils after the reconstruction of drainage dich system is now possible in the studied sites, since the ground cover vegetation has now been characterized.

## Conclusions

- 1. The composition of ground cover vegetation species differed amongst the studied sites. However, the stand factors were divergent, thus influencing the species composition and making it difficult to assess the direct impact of the groundwater level.
- 2. The sites with fully and partially reconstructed drainage ditches had a higher number of species, while the control stand, where no drainage dich renewal had taken place, contained a greater projective cover of bryophyte layer.
- 3. Admixture in canopy layer had a more distinct influence on the characteristics of ground vegetation species than that of the groundwater level.

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# FOREST VEGETATION ON THE ISLAND OF UPURSALA OF LAKE CIRIŠS, LATVIA

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#### Abstract

Only less than one percent of the territory of Latvia is occupied by broadleaved (trees having relatively wide flat leaves) forests. The aim of the research is to assess forest vegetation in the island of Upursala of Cirišs lake. The data is collected in four forest areas of the island. Totally 12 plots, each with an area of  $200 \text{ m}^2 (20 \text{ x} 20 \text{ m})$  have been created. In each plot, the accounting of growing trees and deadwood is carried out. The vegetation is measured in each forest area - the projective vegetation cover and cover of each plant species by tree, shrub, herb and moss layer are determined. The research founds that the average stock of growing trees on the island of Upursala is 565.8 m<sup>3</sup> ha<sup>-1</sup>. The average amount of dead wood is 108 m<sup>3</sup> ha<sup>-1</sup>, it consists mainly of fallen deadwood. Totally 45 species are listed in the vegetation plots, of which seven are determinants of European broadleaved forests. The largest number of determinant species of European broadleaved forests have been observed in stands with mixed forests (aspen - small-leaved lime – pedunculate oak, aspen – Scots pine - pedunculate oak and Scots pine – Silver birch – aspen). It can be argued that these stands will become the European broadleaved forests in the future. **Key words:** lake's island, broadleaved forest, vegetation, dead wood.

## Introduction

Latvia is located in the transition zone between the boreal (northern coniferous forest zone) and nemoral (broad-leaved) forest zone, which is called hemiboreal middle zone (Laiviņš, 2014; Ikauniece, 2017). Old broad-leaved (trees having relatively wide flat leaves) forests in Latvia occupy only 0.04% of the country's territory (Dabas lieguma 'Rušonu...'). Their growing areas are river valleys, slopes of shores and banks of water bodies, lake islands and plains in the areas where broad-leaved forests were spread in ancient period. The geographical location of Latvia and its soils are suitable for broad-leaved forests to be widespread in the country, but due to economic activities, they are rarely found.

During the Atlantic period 6,000 years ago, when the climate became warmer and when the peak of average air temperature was reached throughout the postglacial period, conditions became more suitable for the growth of broad-leaved species. It was during that time when broad-leaved forests appeared in the territory of Latvia (Suško, 1997; Zunde, 1999). As human economic activities increased, the nemoral broadleaved forests gradually disappeared (Suško, 1997). By the end of the 18th century almost all oak forests in Latvia had been cut down for obtaining profit or for construction purposes (Zunde, 1999; Priedītis, 1999). With the cessation of agricultural activities, overgrowing of forest lands started. Most often pine and oak started getting established, the advanced growth was overgrown with broad-leaved species, and the vegetation characteristic of the habitat appeared in the ground cover (Brūmelis et al., 2011). The climate has changed over the past 2,000 years. It has become 2.5 °C cooler and more humid. The soil has become more acidic; consequently, such soil composition is no longer suitable for the growth of broad-leaved forest tree species. This is the reason why fragmented broadleaved forests are found in Latvia (Dzintare, 2001; Daugaviete, 2017).

European broad-leaved forests are characterized by a

deciduous tree climax or completed vegetation. Forest stands, where the proportion of broad-leaved tree species is at least 50% of the total stock, are considered broad-leaved stands (Ek *et al.*, 2002). The natural disturbance of broad-leaved forests is their selfremoval, caused by falling (under the influence of wind) or death of individual trees. In these places, glades or openings in the canopy are formed (Priedītis, 1999; Ek, Suško, & Auziņš, 2002). New groups of trees emerge in these places, the growth of already existing advanced growth trees increases, and under the influence of light tree crowns begin to spread to the sides, thus occupying the free area.

Broad-leaved forests are characterized by a multi-layer uneven-aged stand, trunks covered with moss and lichens, wood of decayed deciduous trees in various stages of decomposition, trees with hollows made by woodpeckers, rich layer of shrubs and advanced growth of deciduous trees, small amount of spruce admixture and deciduous trees with a diameter of more than 30 cm (Priedītis, 1999). In broad-leaved forests, Picea abies (L.) H. Karst., Populus tremula L., Betula pendula Roth, Alnus glutinosa L. and Alnus incana L. can be present in the admixture, while Corylus avellana L. is most common in the shrub layer (Ek, Suško, & Auziņš, 2002). Herbaceous plants and ferns are most common in the ground cover, while there is a large variety of mosses and lichens on tree trunks and branches (Nikodemus et al., 2018). Broad-leaved forests may also contain species typical of boreal forests, such as Trientalis europaea L. and Vaccinium myrtillus L. The so-called old-growth forest species play an important role in broad-leaved forests, they are characterized by slow spread and low preservation capacity. These species include Galium odoratum L. and Carydalis cava L. (Hermy & Verheyn, 2007).

Latvian broad-leaved forests are described as multilayer stands with a rich shrub layer or advanced growth of deciduous trees, where the ground cover also contains a fallen deadwood layer (Priedītis, 1999; Lārmanis, Priedītis, & Rudzīte, 2000). The different habitat species depend on the structural elements of the different forest habitats (Ek, Suško, & Auziņš, 2002, 2002) - growing trees, standing dead trees, snags, fallen deadwood and old trees of different species (Priedītis, 1999). A large amount of deadwood in different stages of decomposition is characteristic of places with little human influence (Ikauniece, 2013). Broad-leaved forests have the highest availability of deadwood (149.5 m<sup>3</sup> ha<sup>-1</sup>). High levels of deadwood are related to the biological age of trees (Liepa, 2021) and the spread of pathogenic organisms (Matisone et al., 2018). Deadwood plays a major role in maintaining diversity, since it provides a habitat for species that cannot exist in another environment, and the diversity of species depends on the stage of wood decomposition.

Oak and lime forests are found in Eastern Latvia and on the largest islands of lakes (Laivinš, 1986). On the islands of Southern Latgale lakes, the forest stand consists of old Betula pendula and Populus tremula together with broad-leaved species typical of the habitat - Quercus robur L., Fraxinus excelsior L. and Tilia cordata Mill. The species that characterize old broad-leaved forests do not dominate the first layer, but are present in the admixture of the first layer. In Latvia, more common are forest stands where the dominant tree species are aspen, birch or spruce, but broad-leaved tree species have formed the second layer or advanced growth. Under favorable growing conditions, broad-leaved tree species will be able to take the place of dominant tree species in the future (Ek, Suško, & Auziņš, 2002). Here, the ground cover is dominated by various herbaceous plant species: in spring - Anemone nemorosa L., Asarum europaeum L., Galeobdolum luteum Huds., Hepatica nobilis Mill. and Stellaria holostea L., in the second half of summer Aegopodium podagraria L. (Dabas lieguma 'Rušonu...', 2017).

It is important to find out in what direction the forests located on the islands of the lakes are developing, because in the future, they will probably be the only places where broad-leaved forests will grow. The aim of the study is to assess the forest vegetation on the island of Upursala of lake Cirišs.

#### **Materials and Methods**

The research site is the island Upursala of lake Cirišs, which is located in Eastern Latvia. Upursala is located in the protected area of the nature park 'Cirīša ezers' 'Figure 1'. It has been a protected nature monument since 1931 (Dabas parka 'Cirīšu...', 2002).

The island has a peculiar, horseshoe shape, and it is the largest island of this lake. Its area is 18 ha, which is 2.54% of the total area of the lake. There are particularly steep slopes with wet depressions in their lower part. There are several shallow shores around the island. In total, there are four distinct terrain elevations on the island, the highest peak of the island is 160.3 m above sea level. Mainly deciduous forests dominate on the island, but there are also over-moist broad-leaved

forests that form in the depressions.



Figure 1. The island of Upursala in lake Cirišs.

The island has a typical continental climate. The average air temperature in January is -7.5 °C, while in July it ranges from +16.5 °C to +17.4 °C, the frost-free period is 140-155 days a year. The amount of precipitation reaches 550-650 mm per year. The eastern part of the island is covered by secondary aspen forests and the western part by pine forests. The habitat mosaic of Upursala is determined by the distinct micro terrain, which rises up to 20 m above the lake level in the southern part. 264 plant species have been found on the island (Dabas parka 'Cirīšu ...', 2002).

Three sample plots were established in each of the four forest compartments. The size of each plot is  $20 \times 20$  m ( $400 \text{ m}^2$ ). In each sample plot, all growing and dead trees (fallen deadwood, standing dead trees and snags) starting with a diameter of 6 cm were measured and the tree species were determined. The stage of decomposition of fallen deadwood was also determined, taking into account the condition of the bark of the fallen deadwood, texture, shape, wood colour and the presence of branches according to the methodology developed by Hunter (1990).

In one sample plot of each forest compartment, an inventory of vascular plant species was carried out by vegetation (trees, shrubs, herbaceous plants and mosses) layers: the total projective cover (%) of each vegetation layer, as well as the projective cover of each individual species (Mueller-Dombois & Ellenberg, 1974).

Microsoft Office Excel programme was used for calculations. The calculations of the indicators of the tree stand structural elements were done using generally accepted formulas in forestry (Liepa, 1996; Dreimanis, 2016).

Univariate analysis of variance was performed to determine the strength of the relationship between the characteristics. The Shapiro-Wilk test (Shapiro & Walk, 1965) was initially used to compare the diameters of the growing trees, in order to find out whether the data obtained correspond to the normal distribution. For further data processing, a non-parametric data processing method was used - the Kruskal-Wallis test (Kruskal & Wallis, 1952).

According to the Raunkiaer formula, an occurrence coefficient was calculated for each species of vascular plants, which reflects the frequency of the species representation in the sample plots (Markov, 1965). The occurrence coefficient determines the constancy index. It was also determined for the species by referencing the number of the plots where the species was found against the total number of sample plots: I (< 21 %), II (21 – 40 %), III (41 – 60 %), IV (61 – 80 %) and V (81 – 100 %) (Mueller-Dombois & Ellenberg, 1974).

The Shannon-Wiener diversity index was calculated to determine the relative abundance (uniformity) of the listed species.

# **Results and Discussion**

In Populus tremula-Tilia cordata-Quercus robur forest stand (PTQ), the total standing volume is 555 m<sup>3</sup> ha<sup>-1</sup>, of which 4.7% (25 m<sup>3</sup> ha<sup>-1</sup>) is the volume of the second layer of the tree stand 'Figure 2'. The age of the forest stand is 83 years. The average diameter of trees in the forest stand is 29.7 cm. The diameter of the trees varies the most from 20 - 38.7 cm, which is smaller than the average in Latvia (49.3 cm) (Nacionālais meža monitorings (National Forest Monitoring), 2022). The average height of trees is 24 m although the National Forest Monitoring data indicate that in the stands where the dominant tree species is aspen and the age of the stand is 81-90 years, the average height of trees is 34.2 m. The trees of largest dimensions in the forest stand are small-leaved lime and common oak. The total number of trees per hectare is 583. By performing the univariate analysis of variance, it was found that the total standing volume of trees growing in the stand differs significantly at different classes of diameter F = 7.5167 > Fcrit =2.6022 (p-value 0.0004 < 0.05). This indicates that in the future there could be more deadwood and more openings in this stand, as currently there is a small number of small dimension trees.

Populus tremula-Pinus sylvestris-Quercus robur stand (PPQ) has the highest total standing volume  $-668 \text{ m}^3$ ha<sup>-1</sup> 'Figure 2'. According to forest taxation data, the age of the forest stand is 98 years. The diameter of the average tree in the forest stand is 38.5 cm. The diameter of trees varies the most from 31.8 - 45.1 cm. The trees of largest dimensions are Scots pine and aspen. The average height of the trees is 26 m. The diameter and height of the average tree in the forest stand, compared to the information provided by the National Forest Monitoring are smaller, but the diameters of individual Scots pine trees are even twice as large (64-86 cm) compared to the average diameters in Latvia. The total number of trees per hectare is 383, of which 78% (300 trees) are trees of the first layer. By performing the univariate analysis of variance, it was found that the total standing volume of the trees

growing in the stand does not differ significantly at different diameter class values F = 0.0729 < Fcrit = 19.4457 (p-value 0.9998 > 0.05).

Pinus sylvestris-Betula pendula-Populus tremula stand (PBP) has the lowest total standing volume. It is 427 m<sup>3</sup> ha<sup>-1</sup> in the first layer and 15 m<sup>3</sup> ha<sup>-1</sup> in the second layer of the forest stand 'Figure 2'. The age of the forest stand is 113 years. The average tree diameter is 31 cm, and the average tree height is 25.4 m. The National Forest Monitoring data indicate that in forest stands aged 111-120 years, where the dominant tree species is Scots pine, the average tree diameter in Latvia is 30.19 cm, height - 22.78 m. The average dimension values of this stand are the closest to what they are on the Latvian scale. Trees with a diameter of 21 - 39.7 cm are most represented, but there are also trees of larger dimensions. The total number of trees per hectare is 442. By performing the univariate analysis of variance, it was found that the standing volume in the stand does not differ significantly at different diameter class values F = 2.4248 < Fcrit = 2.5068 (p-value 0.056 > 0.05). This indicates an even distribution of the standing volume of the trees growing trees in the forest stand.



Abbreviations:



The total standing volume of *Populus tremula-Pinus* sylvestris-Betula pendula (PPB) is 598 m<sup>3</sup> ha<sup>-1</sup> with the largest standing volume of the second floor - 71 m<sup>3</sup> ha<sup>1</sup>, accounting for 12% of the total standing volume 'Figure 2'. According to forest taxation data, the age of the forest stand is 93 years. The average tree diameter of this forest stand is 34.6 cm and the average tree height is 24 m. Here, too, the average indicators are lower than those indicated in the National Forest Monitoring, the average diameter and height of this forest stand are also less than the average diameter (52.76 cm) and height (33.04 m) of aspen (91-100 years old) in Latvia. The diameters of the trees vary mainly from 19.9 - 44.4 cm. The number of trees per hectare is 408, of which 65% are trees of the first layer.

The number of trees is one of the factors affecting tree diameter (Zeide, 2002; Castedo *et al.*, 2005). The greater the number of trees per hectare, the smaller the diameter of the average tree. By performing the univariate analysis of variance, it was found that the standing volume of the trees growing in the stand at different diameter class values does not differ significantly F = 0.6923 < Fcrit = 2.8120 (p-value 0.757 > 0.05).

The largest total volume of deadwood is in the Populus tremula-Tilia cordata-Quercus robur stand - 137.5 m<sup>3</sup> ha<sup>-1</sup>, of which 35 m<sup>3</sup> ha<sup>-1</sup> are fallen deadwood, 53 m<sup>3</sup> ha<sup>-1</sup> <sup>1</sup> snags and 49.5 m<sup>3</sup> ha<sup>-1</sup> standing dead trees 'Figure 3'. The volume of deadwood in the *Populus tremula-Pinus* sylvestris-Quercus robur stand is 117.1 m<sup>3</sup> ha<sup>-1</sup> (Fig.3.). In both stands, the volume of deadwood consists mainly of Populus tremula, damaged by the windbreak. The smallest volume of deadwood is in the Populus tremula-*Pinus svlvestris-Betula pendula* stand -74 m<sup>3</sup> ha<sup>-1</sup> 'Figure 3'. This site also has the smallest average volume of standing dead trees  $-0.7 \text{ m}^3 \text{ ha}^{-1}$ . The average amount of deadwood volume in the Pinus sylvestris-Betula pendula - Populus tremula stand is 100.2 m<sup>3</sup> ha<sup>-1</sup> 'Figure 3'. Compared to the data provided by the National Forest Monitoring, the average volume of deadwood is much larger - in the stands where the dominant tree species is aspen aged from 81 to 90 years, the average amount of deadwood is 96.15 m<sup>3</sup> ha<sup>-1</sup>. In 2022, the average amount of deadwood in Latvia was  $20.57 \pm 0.86$  m<sup>3</sup> ha<sup>-1</sup> (Treimane, 2023). In all sites, the volume of deadwood is sufficient to maintain species biodiversity. The recommended volume of deadwood in broad-leaved forests is 30-50 m3 ha-1 (Müller & Bütler, 2010), but in broad-leaved forests that have developed naturally, it usually exceeds 100 m<sup>3</sup> ha<sup>-1</sup> (Bobiec, 2002). Deadwood is a habitat for many plant and animal species, and it maintains and increases biodiversity (Müller & Bütler, 2010). The diversity of species is greater in places where the deadwood dimensions are larger (Kruys, Jonsson, & Ståhl, 2002; Stokland & Larsson, 2011; Stockland et al., 2012). By carrying out bivariate variance analysis, it was found that there are no significant differences between the total volume of deadwood F = 0.6103 < Fcrit = 4.7571 (p-value 0.6325 > 0.05), and there are also no significant differences between the sites F = 0, 0228 < Fcrit = 5.1432 (p-value 0.9775 > 0.05).

All objects are dominated by fallen deadwood of the III and II stages of decomposition (proportion of 19-31% and 49%, respectively). This indicates gradual dying of the forest stand in a short period of time. It has been proven that the highest number of epiphyte species is on the fallen deadwood in its first three stages of decomposition (Donis, 2020). As the stage of deadwood decomposition changes, species diversity also changes (Stokland, 2001). Studies in Sweden prove that on the deadwood larger than 20 cm there are more than 50% of species, and on the deadwood with a diameter more than 40 cm – 15% of species. Smaller dimension deadwood is important for wood fungi and mosses (Dahlberg, Stokland, 2004; Jonsson *et al.*, 2005). Carrying out univariate analysis of variance, it was concluded that there is no significant difference in the volume of deadwood in different stages of decomposition F = 5.1826 < Fcrit = 23.0555 (p-value 0.007 < 0.05).



Figure 3. The distribution of dead wood in forests stands

Abbreviations:

ATQ Populus tremula-Tilia cordata-Quercus robur, APQ Populus tremula-Pinus sylvestris-Quercus robur, PBA Pinus sylvestris-Betula pendula-Populus tremula, APB Populus tremula-Pinus sylvestris-Betula pendula.

The largest number of plant species is found in the Populus tremula-Pinus sylvestris-Betula pendula stand - 28 species in total. In the stand of Populus tremula-Tilia cordata-Quercus robur and Populus tremula-Pinus sylvestris-Quercus robur - 22 and 21 species, respectively. The smallest number of species (20) was listed in the Pinus sylvestris-Betula pendula - Populus tremula stand. The diversity of herbaceous plant species is affected by the lack of light, as the projective cover of the tree layer in all the sites is over 50%. Common oak, which is one of the indicator species of broad-leaved forests, was listed in all the sites. In oak and lime forests on dry mineral soils, there are on average 31.3 species per 400 m<sup>2</sup> (Priedītis, 1999). The highest diversity index H' = 0.37 was calculated in the stand of *Populus* tremula-Pinus sylvestris-Betula pendula, which is explained by the largest number of occurring species. In the remaining forest stands, the diversity index ranges from 0.32 to 0.34. The diversity index in all four sites is equivalent, since the number of listed species is similar in all forest stands.

Projective cover of the tree layer in all sites exceeds 50%. The smallest projective cover of the tree layer is in the *Populus tremula-Pinus sylvestris-Quercus robur* stand (55%), because relatively large openings have been formed in it due to the death of a large amount of *Populus tremula*. The largest projective cover of the tree layer is in the *Populus tremula-Tilia cordata-Quercus robur* stand (87%), most of it is aspen (45%). Projective cover of shrubs varies from 37% to 95%. The largest projective cover of the shrub layer is in the *Pinus sylvestris-Betula pendula - Populus tremula* stand. It consists mainly of *Corylus avellana* L. – 50%. In other remaining sites, the projective cover of the shrub layer

is similar - about 40%. It is slightly larger than that which is typical of oak and lime forests (Priedītis, 1999). The smallest projective cover of the herbaceous plant layer is in the *Pinus sylvestris-Betula pendula* -*Populus tremula* stand. It is affected by the thick projective cover of the shrub layer, which shades the herbaceous plants growing in the forest stand. The projective cover of herbaceous plant vegetation in the *Populus tremula-Pinus sylvestris-Betula pendula* stand is 99%, which exceeds the canopy of the herbaceous vegetation layer characteristic of boreal coniferous forests (Priedītis, 1999). *Vaccinium myrtillus* L. (23%) and *Vaccinium vitis-idaea* L. (20%) make up the most of it.

Tilia cordata is a species typical of broad-leaved forests, while Populus tremula is more common in boreal forests, but it can also be a transitional species from boreal to broad-leaved forests or vice versa. Overall, the projective cover of the species characteristic of broad-leaved forests is 43%. Since in none of the forest stands the total standing volume of broad-leaved tree species of at least 50% is not reached, currently they cannot be defined as broadleaved forests. Corylus avellana and Lonicera xylosteum L. are listed among the shrub species characteristic of broad-leaved forests (Priedītis, 1999). Shrub layer species characteristic of broad-leaved forests make up 20% of the projective cover. The herbaceous plant layer is dominated by Aegopodium podagraria L. (33%), which is characteristic of fertile deciduous forests (Priedītis, 2014). Unfortunately, the study lacks early summer data.

# Conclusions

1. *Populus tremula* L. and *Pinus sylvestris* L. make up the largest proportion of the total standing volume of growing trees in the forest stands of the island of Upursala of lake Cirišs. Their average volume is 330.7 m<sup>3</sup> ha<sup>-1</sup> and 155.2 m<sup>3</sup> ha<sup>-1</sup>, respectively.

- 2. The standing volume of growing trees at different diameter classes differs significantly in the aspensmall-leaved lime-common oak stand. No significant differences were found in the other stands.
- 3. The volume of deadwood in the forest stands of the island of Upursala of lake Cirišs varies from 74 m<sup>3</sup> ha<sup>-1</sup> 137.5 m<sup>3</sup> ha<sup>-1</sup>. In the forest stands where the proportion of aspen is higher, the largest volume of deadwood was also found. The average proportion of fallen deadwood is 35% (37.9 m<sup>3</sup> ha<sup>-1</sup>), snags 32% (34.3 m<sup>3</sup> ha<sup>-1</sup>) and standing dead trees 33% (35 m<sup>3</sup> ha<sup>-1</sup>).
- 4. The volume of deadwood does not differ significantly between the sites and there are no significant differences within one site either.
- 5. Overall, all five stages of fallen deadwood decomposition have been found in the forest stands of the island of Upursala of Lake Cirišs. The highest proportion of the fallen deadwood is in stage III and stage II of decomposition, which indicates a uniform death of trees in a short period of time.
- 6. In all the research sites, the composition of vascular plant species indicates a development in the direction of European broad-leaved forests. The largest number of forest indicator species of European broad-leaved forests (seven species) has been listed in the *Populus tremula-Tilia cordata-Quercus robur* stand.
- 7. Intensive dying of aspen is taking place in all forest stands, thus giving the opportunity for new species to develop.

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# USE OF AUTOMATICALLY OBTAINED DATA IN THE QUANTITATIVE AND QUALITATIVE EVALUATION OF HARVESTER OPERATOR TRAINING

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# Abstract

The study aims to find out the efficiency of periodic training of the harvester (cut-to-length) operator, using the automatically saved data of the harvester's information system. It has been established that logging service providers and training institutions do not analyze the operator's work before starting the training; therefore, the training is carried out according to certain, standard programs, without going into the previous performance of each trainee operator. The research uses data automatically saved by Ponsse harvesters during the year, obtained from Ponsse Manager. The study found that by using automatically saved data of the harvester information and performing data grouping with subsequent analysis, it is possible to determine the progress in the execution of specific stem processing operations and to identify operations where the instructor should pay increased attention during training. The research analyzed the data of 3 operators, obtained while working with Ponsse harvesters in clear-cutting. In the study, it was found that operator A reduced stem processing time by 3%, labor productivity increased by 15%, and fuel consumption per 1 m-3 decreased by 14% over 3 months. Operator B, after training, saw a 20% reduction in stem processing time, a 13% increase in work productivity, and a 5% increase in fuel consumption 1 m<sup>-3</sup> over 3 months. Operator C had a 10% increase in stem processing time, a 1% increase in labor productivity, and a 2% increase in fuel consumption 1 m<sup>-3</sup> after training.

Key words: harvesting, productivity, training, operator.

# Introduction

Today, with newer, more productive, and more modern machines increasingly entering logging, efficient work is unthinkable without highly qualified operators. To be able to provide the capabilities offered by machines, increase productivity, and reduce fuel consumption and downtime, there is a growing need for highly qualified operators (Malinen *et al.*, 2018) to periodically upgrade the qualifications of operators.

The given study aims to use the automatically saved data of the harvester's information system in the analysis of harvester operators training.

Modern information systems of logging machines allow to save a large amount of data, which can later be used in the analysis of the operators' work (Arlinger & Möller, 2014). Considering that the machine's information system records the working positions very precisely and the reliability of the data is high (Eriksson & Lindroos, 2014), there is no need for the researcher to be near the machine to record the data. One of the first StanForD 2010 data was used in operator productivity analysis by Purfürst & Erler, (2011), later by (Strandgard, Walsh, & Acuna, 2013) and others. Operator productivity is modeled using automatically obtained data (Liski et al., 2020). However, there are not many publications where such a method is used in the analysis of operator training (Strubergs et al., 2022). Such an approach can be used in the analysis of operator training (Palander et al., 2012), by analyzing the time spent in the execution of certain operations before training and later by observing and analyzing the execution time of operations after training, thus evaluating the effectiveness of training. The factors affecting the productivity of the harvester operator are not only the volume of the stem and the species of trees, but the speed and quality of operations have a significant impact on the time and productivity of the stem processing (Zimelis *et al.*, 2015).

# **Materials and Methods**

The study uses automatically obtained data from Ponsse harvesters using Ponsse Manager. Opti 4G 4.780 version installed for harvesters. Harvesters work in the areas managed by the Latvian State Forests in Latvia. The data are obtained for clear-cutting. To get an idea of the effectiveness of the training, data was collected from the harvesters on the work of three operators during the period of two months before the training and three months after the training and grouped by days. Practical work experience as harvester operator, operator A has 5 years, operator B has 1 year and Operator C has 2 years. The data collection period is tied to the operator training day. Operator A has data for the period from November 2021 to June 2022, with a training day on 27 January. For operator B, they were collected for the period from March 2022 to October 2022, with training on May 22. Operator C has data from December 2020 to July 2022, with a training day on February 10.

During the research period, operator A processed 5289 stems before the training, and 21373 stems after the training. Operator B processed 11906 stems before training, and 23523 stems after training. Operator C processed 8857 stems before training and 17342 stems after training.

From Ponsse Manager, data was manually transferred to Microsoft Excel for further data processing.

For each operator, the dynamics of changes in work productivity and stem processing time were determined sequentially by month, by sequentially creating their boxplot graph for each month of work. This way, the changes in mean values and the dispersion of the data are determined. Changes in the execution time of individual operations are determined before and after training, as well as changes in fuel consumption before and after training, both by evaluating changes in fuel consumption  $1 \text{ h}^{-1}$  and changes in fuel consumption  $1 \text{ m}^{-3}$ .

In data processing, statistical indicators were determined, variance analysis was performed and the significance of changes in results was performed.

# **Results and Discussion**

Changes in labor productivity as a result of training Before other data analysis is carried out, the influence of the average volume of the stems is ascertained. For operator A, in the period after training, the average volume of the processed stem increased by 9% (increase in volume is not significant, p=0.44>0.05). For operator B, after the training, the average volume of the processed stem decreased by 9% (here, too, the decrease has no significant effect, p=0.12>0.05). For operator C, in the period after training, the average volume of the processed stem increased by 11%, (the increase is not significant here either, p=0.27>0.05).

Comparing the average labor productivity indicators of the operators calculated by the harvester information system before and after the training, it was obtained that the labor productivity of the operator A after the training increased from  $30.56\pm1.59 \text{ m}^3 \text{ h}^{-1}$  to  $35.15\pm1.51 \text{ m}^3 \text{ h}^{-1}$ , or by 15%, the increase is not significant (p=0.42>0.05). For operator B, the average work productivity increased from 18.74±0.64 m<sup>3</sup> h<sup>-1</sup> to 21.13±0.67 m<sup>3</sup> h<sup>-1</sup> or by 13%. also showing a significant increase (p=0.02<0.05). For operator C, the average work productivity increased from 31.23±2.09 m<sup>3</sup> h<sup>-1</sup> to  $31.39\pm1.51$  m<sup>3</sup> h<sup>-1</sup> or by 0.6%, the increase is not significant (p=0.95>0.05).

To evaluate the dynamics of changes in labor productivity during the research period, a schedule was drawn up for each operator with the dynamics of changes in productivity before and after training. For Operator A, the changes are shown in 'Figure 1'.



Figure 1. Change in productivity of operator Aduring months before and after training.

Looking at the data, it can be seen that before the training, the productivity of operator A decreased, but after the training, it tends to gradually increase. Likewise, after the training, the dispersion of the data decreased and the values became more

concentrated around the average value.

For operator B, the dynamics of changes in work productivity before and after training are shown in 'Figure 2'.





According to the information shown in 'Figure 2', it can be seen that operator B not only increased his productivity after training but also increased the dispersion of data around the average value. In the third month after the training, a sharp increase in the median values is observed, which in general indicates the positive effect of the training. The change in operator C's work productivity in the development sequence is shown in 'Figure 3'.





For operator C, in the first month after training, a decrease in work productivity can be observed, followed by an increase in work productivity, which, however, is not stable. Data dispersion decreased after training.

This information provides a general idea of the impact of the training.

*Changes in stem processing before and after training.* To understand the changes in labor productivity in the investigated time frame, the time spent on stem processing will be analyzed in the future. Similarly, when looking at labor productivity, first of all, the change in the total time spent processing the stem during the researched period will be examined for the operators. Similarly, the change in the total time spent processing the stem during the researched period will be examined for the operators. The change in the time spent by operator A for stem processing is shown in 'Figure 4'.



Figure 4. Operator A stem processing time during months before and after training.

Despite the slight decrease in stem processing time in the first month after training, a gradual increase in stem processing time can be observed in the following period, which, however, did not affect the increase in work productivity after training 'Figure 1', because on average, after training, the average stem processing time of operator A decreased by 3%. However, the reduction in processing time is not significant (p=0.477>0.05). The reduction of the median and data dispersion after training is also positive, which shows that the processing of stems becomes smoother.

Operator B had the greatest effect in reducing stem processing time from training 'Figure 5'.





Operator B's stem processing time after training was reduced by 20% compared to the period before training. Significant time reduction ( $p=3.66e^{-06}$  <0.05). After the training, the processing time of the stems is concentrated around the average value. Therefore, it can be concluded that processing has become smoother and processing times are more concentrated, which indicates the positive impact of the training.

For operator C, the only one examined, the training has negatively affected the processing time of the stems and the processing of the stems has become more uncertain.

For operator C, the only one examined, the training has negatively affected the processing time of the stems and the processing of the stems has become more uncertain. First, the processing time of the stem increased by 10%, the increase in processing time is significant (p=0.032>0.05). Second, the scatter of the data has increased, which may indicate greater variability during stem processing 'Figure 6'.





In the following month, after the training, the numerical value of the maximum stem processing time for operator C increased by 32%, which may indicate difficulties in adapting to the new work methods and unexpected changes in the work process. Over time, the average stem processing time tends to decrease and the other indicators also stabilize.

*Changes in execution time of individual operations* Since the harvester's information system records the time spent on each operation, the effect of training on the average time spent on each operation before and after training can be seen. Thus, it is possible to find out in which positions the training had a positive effect, but where more attention should be paid in the future.

The values of the time spent by operators to perform operations are reflected in Table 1.

According to the data presented in the table, it can be seen that for operator A, a decrease in time

Table 1

consumption can be observed in the operations 'Grabbing the stem' by 6%, 'Pruning' by 6%, and 'Moving branches' by 15%. The reduction of the time spent on all three operations is directly related to the selection of the optimal position of the harvester. A small 6% increase in time to 'Sawing and stacking' could be due to a small assortment of stack placement confusion. However, for operator A, the percentage change in operation completion time after training is not significant, as p>0.05 in all cases.

For operator B, larger and more significant changes in the execution time of operations can be observed. The biggest reduction in the execution time of operations can be observed in the operations 'Moving branches' by 40%, 'Sawing and stacking' by 29%, and 'Felling sawing' by 22%.

Execution times of operator operations										
			Operator A	Operator B		Operator C				
Operation	Periods	Time, s	Time change, %	p- value	Time, s	Time change, %	p-value	Time, s	Time change, %	p- value
Grabbing the stem	Before training	21.5±0.9	-6	0.33	29.1±1.8	15	0.01	24.0±1.4	- 3	0.65
	After training	20.2±0.9			24.7±1.8	-13		24.7±0.9		0.05
Felling sawing	Before training	5.3±0.1	3	0.45	7.3±0.3	22	8 400-08	3.7±0.1	- 10	0.01
	After training	5.4±0.1			5.7±0.1	-22	8.49e <sup>-08</sup>	4.1±0.1		
Sawing and stacking	Before training	10.6±0.3	6	0.21	26.7±1.3	-29 2	2.63e <sup>-09</sup>	8.9±0.24	- 4	0.28
	After training	11.2±0.4			18.9±0.5			9.3±0.2		
Pruning -	Before training	11.2±0.4	-6	0.18	16.7±0.6	15	0.0001	8.3±0.2	- 19	0.0001
	After training	10.6±0.2			14.1±0.3	-13	0.0001	9.9±0.3		
Sawing	Before training	3.5±0.1	2	0.22	3.3±0.1	12	0.000	2.7±0.14	2	0.52
	After training	After 3.6±0.1	0.32	3.7±0.1	12	0.009	2.8±0.1	5	0.55	
Moving branches	Before training3.6±0.3After training3.1±0.3	15	15 0.10	4.5±1.0	40	0.022	6.0±1.1	24	0.18	
		-15	0.19	2.7±0.1	-40	0.022	8.1±0.9	34	0.10	

Execution times of operator operations

Unlike operators A and B, operator C, despite a slight increase in work productivity 'Figure 2' and a decrease in data dispersion after training, has an increase in the execution time of operations in all operations. When performing 'Felling sawing' and 'Pruning operations', the increase in execution time is significant. For operators A and C, the time of 'Moving branches' increased by 34%, which could indicate inadequate development technology and unsuccessful selection of the harvester position, as a result of which the stem is pruned in an unexpected place and, to comply with the requirements of logging technology, additional time is consumed for moving branches. Legally, the second operation which significantly, p=0.0001<0.05, increased the execution time of the operation by 19% is 'Pruning'.

# Fuel consumption analysis

Ponsse Manager captures the total fuel consumption in the period under review, without dividing the fuel consumption in the execution of individual positions. Therefore, we get the total fuel consumption for analysis. This is enough to observe the general trend of fuel consumption before and after training. To describe the effectiveness of training, two parameters are considered: fuel consumption for processing 1m<sup>3</sup> stems and fuel consumption in liters per hour. On the left side of 'Figure 6', it can be seen that operator A, after the training, significantly, p=0.026<0.05, increased by 2% the average fuel consumption 1 h<sup>-1</sup> and the data dispersion decreased. On the other hand, on the right side of the picture, it can be seen that fuel consumption per m<sup>3</sup> of production has decreased significantly, p=0.044<0.05, after the training. The reduction in fuel consumption amounts to 14%, as well as reduced data dispersion around the average value. Looking at these two factors together, it can be concluded that after the training for operator A, the harvester was loaded more fully and by producing more production, fuel consumption and production units (m<sup>3</sup>) decreased 14%, which indicates an increase in engine load. After the training, operator B's fuel consumption per unit of production also increased by 5%. However, this increase in fuel consumption is not significant, p=0.323>0.05.



Figure 6. Chang Change in operator A's fuel consumption over time periods before and after training.

Looking at the fuel consumption changes that occurred as a result of operator B's training 'Figure 7', it can be seen that after the training, the fuel consumption per unit of time increased significantly,  $p=6.67e^{-12} < 0.05$ . Fuel consumption increased by



Figure 7. Change in operator B's fuel consumption over time periods before and after training.

The smallest effect on fuel consumption after training can be observed for operator C 'Figure 8'. Contrary to operators A and B, operator C's fuel consumption per time unit is insignificant, p=0.782, it decreased by 1%. On the other hand, the fuel consumption per volume unit increased significantly, p=0.838>0.05, by 2%. By performing a regular analysis of the operator's work records, using automatically obtained data, it is possible to obtain information in which stem processing operations the operator needs to pay more attention to prevent errors in the execution of operations and increase work productivity.



Figure 8. Change in operator C's fuel consumption over periods before and after training.

By using the manufacturer's program in the analysis of the operator's work, it is possible to evaluate each stem processing operation. In the program, it is possible to filter additional data by stem volume; however, it is not possible to separate individual tree species, which could provide more accurate information about the effect of the species on productivity. It is necessary to continue the research by creating opportunities in the analysis of labor productivity by including such variables as the species of trees and the nomenclature and quantity of the assortments to be prepared.

## Conclusions

- 1. After the training for operator A, the processing time of the stem decreased by 3%, but the labour productivity increased by 15%, while the fuel consumption per unit volume decreased by 14%
- 2. A gradual increase in work productivity and a decrease in fuel consumption can be observed.
- 3. After the training, operator B saw a 20% decrease in stem processing time and a 13% increase in work productivity during the considered period, however, there was a 5% increase in fuel consumption per m<sup>3</sup>.
- 4. Operator C has observed uncertainty after the training, because the stem processing time has increased by 10%, work productivity has increased by 1%, and fuel consumption has also increased by 2%.
- 5. The analysis of changes in the execution time of operations allows us to find solutions for reducing the execution time of operations.

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# DETECTION OF CORONAVIRUS AMONG DOMESTIC ANIMALS

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Abstract

This article presents the results of studies on biological samples collected from 640 swabs taken from dogs and cats across various regions of the Republic of Kazakhstan. These samples were part of a monitoring study on the spread of coronavirus among domestic animals. Total RNAs were isolated using the magnetic sorption method with the ALPREP kit and subsequently analyzed with the ALSENSE-SARS-CoV-2 RT-qPCR kit. Real-time RT-PCR analysis revealed that 104 samples tested positive within 22–37 amplification cycles. These positive samples were then cultured in Vero cell lines to confirm the presence of the virus. The biological activity of the resulting virus-containing suspension was determined using the Reed-Muench method. During cultivation, one viral isolate with a biological activity of  $5.83\pm0.08$  lg TCID<sub>50</sub>/ml was obtained. A microphotograph of the virus was taken using an electron microscope to determine its size, shape, and structure, which confirmed its morphology corresponding to the Coronaviridae family. The data obtained further indicate that domestic animals can suffer from and carry coronavirus. It is becoming increasingly evident that the virus can infect and replicate in the organs of various farm and domestic animals.

Key words: biological samples, coronaviruses, PCR analysis, RNA, domestic animals, Vero cell culture, electron microscopy.

## Introduction

Coronaviruses comprise a large family of viruses known to infect both humans and animals (Denis et al., 2020: Prince et al., 2021: Considerations, 2020: Cohen. 2020). However, evidence of mutual transmission between humans and animals remains inconclusive. In this regard, the global scientific community is investigating the potential for crossspecies virus transmission. While human-to-human transmission is well-established, the dynamics of transmission between humans and animals are less clear. The threat is not only to human health, but it also poses a significant risk to the animal population. There are numerous reports indicating a high likelihood of COVID-19 transmission from humans to animals, leading to an increase in pet abandonment. Another concern is the possibility of reverse zoonosis, where the COVID-19 virus could be transmitted back to humans from pets such as cats and dogs.

Evidence suggests that the virus may initially circulate in bats before being transmitted to humans via an intermediate host, raising new questions about the potential for human-to-animal transmission. Several instances of this virus transmitting from infected humans to animals have been documented (Ng & Hiscox, 2020). Literature indicates that SARS-CoV-2 infections in animals can range from asymptomatic to symptomatic, with signs varying from mild respiratory and gastrointestinal symptoms to severe conditions such as pneumonia and death (Cui *et al.*, 2022).

To understand the spread of coronavirus among animals and explore the possible evolutionary connections between humans and animals, extensive research, including virus isolation, cultivation, and analysis of the biological and physicochemical properties of viruses isolated from animals, is essential. In this context, Kazakh scientists have explored the susceptibility of various cell lines to the coronavirus. Their research involved 11 different primary and continuous cell lines, finding that the coronavirus caused cytopathic effects in Vero cell cultures (Zhugunissov *et al.*, 2022). This highlights the need for further research to optimize the cultivation of virus-containing material in Vero cell cultures. This study aims to examine the biological properties of material containing the virus isolated from domestic dogs.

# **Materials and Methods**

## Sampling and Transportation

Sampling from domestic animals exhibiting clinical signs of coronavirus infections was conducted in compliance with the applicable regulatory legal acts in the Republic of Kazakhstan (Prikaz, 2015). Specialists adhered to prescribed procedures and biosafety regulations during sampling, including the use of protective clothing, goggles, gloves, disinfectants, and appropriate handling techniques.

During swab collection, animals were securely restrained to ensure stable fixation. Dry, sterile cotton swabs were used to collect samples from the nasal cavity, oropharynx, rectum, and conjunctiva mucous membranes. Throughout the expedition, swabs were stored in liquid nitrogen.

#### Clinical Samples

For this study, a total of 640 clinical samples (including mouth washes, rectal, nasal, and ocular swabs) were collected from 160 diseased domestic animals (dogs and cats) across various regions including Turkestan, Karaganda, East Kazakhstan, Astana, and Almaty.

*Total RNA extraction* was performed using the ALPREP kit, employing the magnetic sorption method according to the manufacturer's protocol (Ali *et al.*, 2017).

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*Virus identification* via real-time PCR was conducted using the 'ALSENSE-SARS-CoV-2–RT-qPCR' kit, following the manufacturer's instructions (Wu *et al.*, 2020).

#### Virus isolation in cell culture

Virus isolation in Vero cell culture was achieved through blind passaging for a minimum of three generations (Zhugunissov et al., 2022). The infectious activity of the virus was determined by titration following the Reed-Muench method (Wurtz et al., 2021) in a Vero cell culture grown in a 96-well culture microplate. Serial 10-fold dilutions of the virus stock ranging from 10<sup>-1</sup> to 10<sup>-8</sup> were prepared in DMEM supplemented with 2% PBS, 100 U/ml penicillin, and 100 µg/ml streptomycin. Subsequently, 100 µl of each dilution was added to the wells. Cells were incubated at 37°C in a 5% CO<sub>2</sub> atmosphere for 7 days, and cytopathic effects were assessed using an inverted microscope. The titer of virus-containing material was calculated using the Reed-Muench formula and expressed in lg TCID<sub>50</sub>/ml (Reed & Muench, 1938; Korochkin et al., 2010; Zhugunissov et al., 2022).

# Electron Microscopy of Viruses

The virus-containing material was concentrated by ultracentrifugation using a Himac CS-150FNX ultracentrifuge (Japan) at 366,000 g for 20 minutes. After centrifugation, the supernatant was discarded, and the sediment was resuspended in 1X PBS buffer to a volume of 100  $\mu$ l. Preparations for electron microscopy were made by adsorbing onto copper grids coated with a formvar substrate reinforced with carbon. Negative contrast was achieved using a 2% aqueous solution of phosphotungstic acid, and the samples were examined using a transmission electron microscope JEM-100 CX-II JEOL (Japan) at an accelerating voltage of 80 kV at various magnifications. Photographs were captured from developed and fixed negatives using an Azov photo enlarger.

## Statistical Analysis

Statistical processing of the data was performed using the GraphPad Prism 8 software package. The data were subjected to analysis using Student's t-test, deemed reliable at p < 0.05 (Ashmarin, Vasiljev, & Ambrosov, 1975).

## **Results and Discussion**

For this study, 640 samples were used to monitor coronavirus infection among domestic animal species from nurseries in Turkestan, Karaganda, East Kazakhstan, Astana, and Almaty. From the real-time PCR results, it was established that out of the 640 biological samples studied, 104 showed positive results for the presence of the virus, see 'Figure 1'. The positive control sample gave a positive result at cycle 22 (Ct-22.00), compared with the fastest detection in sample No. 5 at cycle 21 (Ct-21.88). This sample was isolated from the rectum of dog No. 5. The remaining samples were detected within cycles 25-37 (Ct-25.23 - Ct-37.27).



Figure 1. Map of samples with sampling sites. The virus was identified in selected samples using real-time PCR.

Next, the samples that showed a positive result in the PCR analysis (Nos. 1-104) were seeded on Vero cell culture. Observation of morphological changes in cell culture samples was carried out over 4 days. No cytopathogenic effect (CPE) was detected in any of the biological samples at the first passage level. The culture suspension was then frozen at  $-50 \pm 0.5^{\circ}$ C.

Subsequently, blind passaging was performed for three generations. Cell cultures were infected with a thawed virus-containing suspension in the following passage. At the third passage level, on the third day of observation, rounding and destruction of cells in samples No. 5, 7, and 10 were noticeable, indicating the formation of virus CPE. All samples were then sent to the fourth passage. Observation of morphological changes continued over 4 days. On the fourth day, changes in cell shape, such as swelling, rounding, or thinning, were noticeable only in sample No. 5, indicating the formation of CPE. A cytopathogenic agent could not be detected in the other biological samples, leading to their exclusion from further studies. Sample No. 5 was passaged until the eighth passage with results presented in 'Figure 2'.





From the data obtained in 'Figure 2', it is evident that at the eighth passage level, monolayer destruction occurred through detachment/desquamation of the affected cells 48-72 hours after the appearance of the first signs of cytopathology. From the data presented in 'Figure 1', it is clear that at the fourth passage level, biological sample No. 5 (rectal wash) showed CPE of the virus in the Vero cell culture starting from the third day after infection. As observed in the figure, in subsequent passage levels, the number of rounded cells increases, while the number of spread-out cells on the adhesion surface (in the monolayer of cell culture) decreases. Pockets of emptiness form due to detached cells, and there is an increase in intercellular space compared with the control culture.

Next, the biological activity of the studied material was determined at all passage levels. The results of a comparative analysis of biological activity are presented in 'Figure 3'.



Figure 3. Comparative analysis of the biological activity of the virus in Vero cell culture using the Holm-Sidak method revealed statistically significant differences across passages 4 to 8. Significant differences in biological activity were observed between passages 5 and 6 (p = 0.000202), between passages 6 and 7 (p = 0.024896), and between passages 7 and 8 (p = 0.024896).

The results indicate that the viral material in the studied cell culture samples increases in concentration from one passage to the next, with average values reaching  $5.83\pm0.08$  lg TCID<sub>50</sub>/ml. The presence of the virus was additionally confirmed by electron microscopy, see 'Figure 4'.



Figure 4. Electron microscopy image of the virus. The image was taken at 10,000 times magnification on a transmission electron microscope JEM-100 CX-II JEOL (Japan).

As observed in 'Figure 4', the virus exhibits a spheroid shape with a diameter of 120-160 nm. Virions possess a lipid envelope with club-shaped peplomers, 5-10 nm

in length, formed by trimers of protein S. These peplomers, resembling the teeth of a crown, give the name to the entire family Coronaviridae.

# Discussion

SARS-CoV-2, which is believed to have originated from bat coronaviruses, enters host cells through the ACE2 receptor. This process shows varying affinities across different animal species. Infected pets display positive SARS-CoV-2 PCR results and develop antibodies, often mirroring respiratory symptoms observed in their owners, which suggests interspecies transmission (Ferasin *et al.*, 2021).

Among domestic animals, alpha, beta, and delta coronaviruses are notable causative agents of infections. These viruses exhibit host specificity and diverse clinical presentations. For instance, alpha coronaviruses affect dogs (enteric form), cats, pigs (vector-borne gastroenteritis), minks, and ferrets, while beta coronaviruses cause diseases in cattle (BCoV), dogs (respiratory form), horses, and pigs (hemagglutinating encephalomyelitis). Delta coronavirus primarily infects pigs (Dzhavadov *et al.*, 2020; Nagornyh, Tyumencev, & Akimkin, 2020; Andreeva & Nikolaeva, 2021).

Some animal species have tested positive for SARS-CoV-2, mainly after close contact with humans infected with SARS-CoV-2. These detections include various animals such as birds, various primates, reptiles, ungulates, felines, other carnivores, and domestic dogs (Andreeva & Nikolaeva, 2021).

In this study, coronavirus circulation was detected in stray dogs from an animal detention facility in Almaty. Clinical manifestations in animals, similar to humans, include cough, sneezing, shortness of breath, nasal and eye discharge, vomiting or diarrhea, fever, and lethargy, with asymptomatic infections also documented (Perera *et al.*, 2021).

Clinical samples from dogs' rectum, oropharynx, and nose were used for research. Based on the PCR results, a coronavirus isolate with a suspected SARS-Cov-2 species was identified, which was further characterized by real-time PCR and electron microscopy. This revealed the size, shape, and morphology of the virus.

Vero cell culture was utilized for virus isolation and cultivation due to its rapid adaptation for coronavirus, facilitating the exploration of biological, moleculargenetic, and physicochemical properties essential for epidemic prevention and diagnosis (Zhugunissov *et al.*, 2022).

Isolation of the virus is crucial to determine and study its biological, molecular, and physicochemical properties since obtaining a new current strain of the virus can help prevent a possible epidemic by creating relevant means of prevention and diagnosis.

As is known today, the biological, molecular-genetic, and physicochemical properties of coronavirus

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isolated from pets and animals have not been sufficiently studied. There is no complete information about what evolutionary role pets and animals play in spreading coronavirus in nature (Gautam *et al.*, 2020). The results of this study highlight the optimal cultivation conditions required for isolates from animals, namely an incubation temperature of 35-37°C and an incubation time of 48-72 hours, facilitating the full manifestation of virus CPE in Vero cell culture.

Additionally, literature reports have demonstrated the permissiveness of various laboratory cell lines to SARS-CoV-2 growth. The study showed that virus growth was observed on 7 cell lines: 6 monkey cell lines: VERO E6, VERO 81, VERO SLAM, MA104, LLC-MK2, BGM and 1 human cell line Caco-2. Cytopathogenic effects are variable: 48-72 hours pass from the lysis of the cell monolayer to the absence of a cytopathogenic effect. In their opinion, the penetration of coronaviruses into cells depends on the spike protein (S) binding, which can infect not only various human tissues but also animals (Diaz *et al.*, 2020).

While some literature suggests dogs exhibit low susceptibility to SARS-CoV-2, recent reports of infected pet dogs from different regions indicate the possibility of transmission through contact with infected humans. Although these dogs showed no clinical signs, our study focused on animals presenting with diarrhea, lacrimation, and excessive salivation, suggesting potential variations in viral pathogenicity (Shi *et al.*, 2020; Leroy, Ar Gouilh, & Brugere-Picoux, 2020; Csiszar *et al.*, 2020; Loeb 2020; Goumenou,

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Given the similarity of ACE2 receptors in dogs to human ACE2 (hACE2) receptors, raising concerns about their role as potential carriers, further investigations are warranted. However, current evidence does not support the transmission of the virus from infected dogs to animals or humans.

The obtained data will be used to further experiments aimed at determining the pathogenicity of coronavirus viral biomass in vivo and conducting genetic studies.

# Conclusions

- 1. This study analyzed 640 swabs obtained from domestic pets, revealing that 104 samples tested positive for the presence of coronavirus. After reproduction in Vero cell culture, a coronavirus viral biomass with a biological activity of 5.83±0.08 lgTCID<sub>50</sub>/ml was isolated from a dog.
- 2. The data obtained indicate the potential for coronavirus infection in pets, highlighting the necessity for further research in this area.

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# SAMBUCUS NIGRA FRUITS AND THEIR PROCESSING SOLUTIONS: A REVIEW

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# Abstract

Sambucus nigra has garnered attention in the food industry for its natural colouring and antioxidant properties, mainly due to its high content of anthocyanins, other polyphenols, and vitamins. These bioactive compounds not only contribute to the nutritional impact of food products, but also make it possible to replace synthetic additives that meet the current consumer demand for natural and functional foods. This study provides an overview of the bioactive compounds in *Sambucus nigra* (black elder) fruits, highlighting their potential health benefits and toxicity concerns. It examines the effect of different processing technologies on the phenolic and cyanogenic glycoside composition of elderberry, emphasizing the need to balance microbial decontamination with the sensory quality and nutritional value of food products. The study also reviews the mechanism of ultrasonic inactivation of microorganisms and the potential of fermentation to reduce toxic compounds in *Sambucus nigra* fruits, thus contributing to the improvement of food safety and nutritional quality, emphasizing the importance of considering the potential limitations of ultrasound and the use of combined methods to increase efficiency while minimizing the negative impact on both the product and the consumer. Additionally, the study discusses the significance of selecting appropriate processing methods to ensure the safety of elderberry products, given the presence of potentially harmful cyanogenic glycosides and lectins, which can be mitigated through heat treatment and fermentation.

Key words: Black elderberry, cyanogenic glycosides, fermentation, lectins, ultrasound treatment, polyphenols.

# Introduction

Sambucus nigra L., commonly known as black elderberry, is a member of the Adoxaceae family and is native to the northern hemisphere, particularly in Europe, Northern America, and Western Asia. It is a large bush or a small tree that can reach a height of up to 10 meters, with small white flowers grouped in cymes. The flowering season typically occurs in June and July, usually in the plant's third or fourth year. Black elder is known for its preference for soils rich in nitrogen and calcium compounds. Although it has a particular fondness for alkaline environments, it can adapt to a wide range of soil types, thriving in conditions with pH from 4.2 to 8.0. The chemical composition of Sambucus nigra fruits is influenced by factors such as climate and agricultural practices (Bartak et al., 2020).

The scientific literature mentions different subspecies of elderberry, including *Sambucus nigra* subsp. *canadensis*, which is native to North America, and *Sambucus nigra* subsp. *nigra*, which is native to Europe. The European elderberry subspecies, *Sambucus nigra*, is known for its medicinal attributes (Thomas *et al.*, 2015; Bartak *et al.*, 2020; University of California Agriculture and Natural Resources 2024).

Elderberry is rich in anthocyanins, polyphenols, and vitamins, making it suitable for use as a natural colourant and antioxidant in the food industry. The high content of anthocyanins in elderberry makes it a promising natural colourant, contributing to the blue, purple, and red colour (Domínguez et al., 2021). Additionally, elderberry's bioactive compounds, including anthocyanins, contribute to its high antioxidant capacity, which can increase the shelf-life of food products. Numerous studies have confirmed the high antioxidant activity of elderberry and its abundance of important biologically active components, such as polyphenols, primarily

anthocyanins, flavonols, and phenolic acids (Thomas *et al.*, 2015; Bartak *et al.*, 2020; Domínguez *et al.*, 2021; Borodušķe *et al.*, 2022; Ferreira *et al.*, 2022). These compounds not only provide antioxidant properties but also offer potential as natural colourants for various food applications (Domínguez *et al.*, 2020, 2021; Przybylska-Balcerek *et al.*, 2021).

However, it should be considered that the content of biologically active substances valuable to human health can change considerably depending on the chosen processing technology. Selecting the most suitable processing method for *Sambucus nigra* fruits is crucial to ensure the safety of the final products for consumers. This is particularly important due to the presence of cyanogenic glycosides and lectins in the fruits, which pose health risks if not properly processed. The aim of the study was to review available scientific information on the composition of the *Sambucus nigra* fruits and the effect of different processing technologies on cyanogenic glycosides.

## Materials and Methods

In total, 30 scientific publications or articles were selected and examined, of which 29 were published in the period from 2015 to 2023, and 1 article was published in 1997. The data was collected from various academic databases and literature sources, including Google Scholar, Taylor & Francis eBooks, Web of Science, PubMed, and Science Direct. The following key words and combinations of key words were used in the most relevant literature search: Sambucus nigra, black elderberry, cyanogenic glycosides, sambunigrin, ribosome inactivating protein, lectin, allergen, food processing technique, ultrasonic treatment. A total of 108,713 records were recognized by mentioned database searchings, of which 303 potential articles were examined more closely. In total, 30 full-text literature sources were selected and examined, as well as literature related to

the field of study on nutritional value and compositional characteristics and expert opinions. The study employed a semi-systematic approach in its research methodology within the field of food science.

# **Results and Discussion**

Nutritional and bioactive components, health benefits Fruits of black elderberry play a vital role in strengthening the human body and improving immunity. Their fruit and flower extracts possess antiviral and anti-inflammatory properties (Borodušķe et al., 2022). Elderberry fruits contain such biologically active substances as protocatechuic acid, chlorogenic acid, rutin, quercetin-3-O-hexoside, quercetin and ursolic acid (Terzić et al., 2023). It is a source of anthocyanins and valuable other polyphenols, which are utilized in food industry as dyes and bioactive substances (Ferreira et al., 2019; Banach et al., 2021). In vitro tests confirm the significant antioxidant activity of berry extracts. It also has been found to be effective inhibitors of  $\alpha$ -amylase and  $\alpha$ -glucosidase, which can help in reducing blood glucose levels (Terzić et al., 2023). Sambucus nigra fruits have a high potential in reducing cellular oxidative stress and preventing inflammatory processes (Ferreira et al., 2022). Studies suggest that extracts from Sambucus nigra can serve as a source of bioactive compounds for the creation of new active products, biologically including pharmaceuticals and functional food ingredients (Ferreira-Santos et al., 2022; Terzić et al., 2023).

The major protein found in elderberry fruits is a lectin derived from a truncated type II ribosome-inactivating protein (RIP), known as *Sambucus nigra* agglutinin IVf or SNAIVf (Van Damme *et al.*, 1997).

The fruits of the *Sambucus nigra* plant contain ribosome-inactivating proteins (RIPs), which are specialised proteins that target cells or substances that many pathogens bind to. These RIPs demonstrate greater therapeutic potential compared to those identified in other plant species. Additionally, black elderberries contain peptic polysaccharides, which have the ability to activate macrophages and other antiviral substances, such as phenolic compounds. These compounds have been shown to exhibit antiviral activity against influenza, human coronaviruses, and other viruses (Bartak *et al.*, 2020).

Consumption of type II RIP in high concentrations has toxic effects. Although elderberry species have been reported to contain significant amounts of type II RIPs, *Sambucus nigra* species contain type II RIPs which are known as non-toxic. However, the amount of consumption should be considered (Torero *et al.*, 2015; Aliç *et al.*, 2021).

## Toxicity concerns

It is important to note that the plant contains potentially toxic cyanogenic glycosides, particularly in the bark, leaves, seeds, and unripe fruits (Appenteng *et al.*, 2021). The amount of these compounds depends on growing conditions (Mahboubi, 2021). Symptoms of

cyanide poisoning from these glycosides can include nausea, vomiting, diarrhoea, and even coma (Appenteng *et al.*, 2021).

Cyanogenic glycosides are glycosides from which hydrolytic enzymes produce hydrocyanic acid (De Vries, 2021). Cyanogenic glycosides are naturally occurring plant molecules (secondary plant metabolites of nitrogen) (Jeyakumar & Lawrence, 2022) consisting of a sugar moiety, an aglycone, and a  $\beta$ -hydroxynitrile. The saccharide group can consist of a monosaccharide, such as glucose, or a disaccharide, such as gentiobiose and vicyanose. Glycosidic bonds within saccharides can be hydrolyzed by glycosidases. Additionally, the nitrile in saccharides can be further degraded by lyases to form hydrogen cyanide and an aldehyde, ketone, or acid. For instance, the cyanogenic glycoside sambunigrin, found in black elderberries, is composed of the aglycon L-mandelonitrile and the sugar part D-glucose (De Vries, 2021).

The presence of cyanogenic glycosides in the fruits of Sambucus nigra is uncertain (Appenteng et al., 2021). However, Appenteg et al. (2021), in the study of cyanogenic glycosides in American elderberry, found that their concentration was generally low and at a level that does not pose a threat to consumers of fresh and processed American elderberry products. The authors also observed that the pattern of the results aligns with the fact that elderberry juice, regardless of being American elderberry or Europen elderberry, exhibited very low levels of cyanogenic glycosides (Appenteng et al., 2021). Rodríguez Madrera & Suárez Valles (2021) reported that the highest amounts of sambunigrin and prunasin were present in the older leaves of the plant of Sambucus nigra, which were 20.7 mg g<sup>-1</sup> and 0.8 mg g<sup>-1</sup> dry matter, respectively. On the other hand, the amount of sambunigrin in fruits was  $0.3-0.4 \text{ mg g}^{-1}$  dry matter, but the levels of amygdalin and prunasin were below the detection limit (Rodríguez Madrera & Suárez Valles, 2021).

In elderberry products, sambunigrin is the most common compound among cyanogenic glycosides (Senica *et al.*, 2016). Sambunigrin is structurally similar to prunasin (Anjum *et al.*, 2022).

Hydrocyanic acid is considered toxic to humans, animals and microorganisms. In humans, lethal doses range from 0.5 to 3.5 mg per kg of body weight (De Vries, 2021). Deaths in humans and animals have been reported from consumption of plants containing about 500 mg hydrogen cyanide per  $100 \text{ g}^{-1}$  seed. Several herbivores have been found to tolerate hydrogen cyanide. Animals can induce rapid detoxification of some cyanogenic glycosides by rhodanese (Anjum *et al.*, 2022).

Another harmful compound found in *Sambucus nigra* are lectins, which are a type of protein that can bind to specific carbohydrate molecules. In the case of *Sambucus nigra*, lectins are found in various parts of the plant, including the bark and fruit.

Elderberry lectins, including Sam n1, are part of a broad family of allergens. The presence of these lectins

in elderberries raises concerns regarding their role as allergens (Jimenez et al., 2017). In the context of food safety and allergen labelling, allergens like Sam n1 must be identified and assessed for their risk to consumers. The Sam n1 allergen shares a high degree of amino acid sequence homology with Sambucus lectins related to the Sam n1 allergen. This similarity raises concerns about the potential for cross-reactivity with other allergens and the overall safety of consuming elderberry products for individuals with allergies (Jimenez et al., 2013). The Codex Alimentarius, a collection of internationally recognized standards and guidelines related to food safety, has established a priority allergen list to guide the labelling of food products (FAO & WHO, 2022). While Sam n1 is not explicitly mentioned in the global priority allergen list, such allergens in food products necessitate consideration by food manufacturers and regulatory bodies to ensure consumer safety. Studies have shown that Sambucus nigra lectins are resistant to digestion unless they are heat-pre-treated. This suggests that the lectins can reach the small intestine mostly intact if not subjected to heat, which could have implications for their potential effects on the body (Jimenez et al., 2017). Heat treatment of elderberry lectins makes them more sensitive to pepsin attack, which is important for fruit preparations to retain healthy properties without the adverse effects of the lectins (Jimenez et al., 2017).

However, some positive properties of lectins are known, such as lectins found in *Sambucus nigra* fruits have protective effects against heavy metals and *Bacillus subtilis* (Aliç *et al.*, 2021).

Processing methods and their effects on food products Thermal processing is widely used in the food industry to ensure the safety of products by reducing or destroying microbial and enzyme activity (Aaliya *et al.*, 2021).

The composition of elderberry phenolics and cyanogenic glycosides is significantly altered during processing. For instance, the levels of phenolics decreased from 958 mg kg<sup>-1</sup> in unprocessed control fruits to  $343 \text{ mg kg}^{-1}$  in elderberry liqueur,  $337 \text{ mg kg}^{-1}$  in spread,  $162 \text{ mg kg}^{-1}$  in tea, and  $114 \text{ mg kg}^{-1}$  in elderberry juice. Moreover, higher temperatures (100–105 °C) not only reduced the content of beneficial compounds due to the decomposition of substances but also decreased the levels of harmful cyanogenic glycosides by 44% in elderberry juice, 80% in tea, and as much as 96% in elderberry liqueur and spread (Senica *et al.*, 2016; Appenteng *et al.*, 2021).

While it is highly effective for microbial decontamination, it is important to balance the intensity of heat treatment to maintain the sensory quality and nutritional value of the food products. High-temperature treatment accelerates degradation and diminishes the sensory and nutritional quality of products. Therefore, mild heat treatment (40–60 °C) is preferred to minimize quality loss. However, mild heat

treatment alone is not sufficient for microbial decontamination and is often used in combination with other technologies such as pulsed electric field, highintensity ultrasound, ultraviolet radiation, non-thermal plasma, electrolyzed water, organic acids, and essential oils. Combining various thermal processing methods with non-thermal techniques can create a synergistic effect against microorganisms, contributing to the optimization of bacterial decontamination in food products (Aaliya et al., 2021). The study by Zhong et al. (2021) explored the effectiveness of ultrasonic pre-treatment (UPT) in reducing the levels of cyanogenic glycosides and hydrogen cyanide in cassava. The research found that a 10-minute UPT could considerably enhance the elimination of these compounds from cassava. Specifically, the study reported that under optimal conditions of 45 °C and 81 W for 10 minutes, UPT was able to remove 40% of hydrogen cyanide and 25% of cyanogenic glycosides from cassava juice.

Zhong et al. (2021) in the study proposed that the mechanisms of elimination for hydrogen cyanide and cyanogenic glycosides differ. Hydrogen cyanide was directly reduced by the ultrasound treatment, while the reduction in cyanogenic glycosides was indirectly achieved through the promotion of enzymatic hydrolysis. This enzymatic process is facilitated by βglucosidase, an enzyme responsible for breaking down cyanogenic glycosides into less harmful components. The activity of  $\beta$ -glucosidase was found to increase by 18% following sonication, indicating that ultrasound not only helps in directly reducing harmful compounds, but also enhances the natural detoxification processes within the cassava (Zhong et al., 2021).

Ultrasound treatment not only reduces the content of cyanogenic glycosides, but also increases the phenolic content of the product. In the study conducted by Nascimento *et al.* (2021), the focus was on evaluating the effectiveness of ultrasound treatment as a method for extracting antioxidant phenols from the fruits of *Sambucus nigra* and *Punica granatum*. The research compared the efficiency of fermentation and ultrasound-assisted extraction techniques, concluding that ultrasound treatment is a significantly more effective method for phenol extraction.

Microorganisms are an important aspect regarding food safety. They can be beneficial in the production of food and contribute to its quality, but they can also cause spoilage and foodborne illnesses if not properly treated.

The mechanism of ultrasonic inactivation of microorganisms is a result of many complex physical processes based on fast-changing mechanical and extrusion of the intracellular matrix, ultimately killing the microorganisms. Inactivation of microorganisms by ultrasound depends on factors including ultrasonic power and wave amplitude, temperature, the volume of the sample, composition and physical properties of food, and type and characteristics of the microorganisms. However, there are limitations to the application of ultrasound in food processing, such as the problem of heat generation and its low efficiency in inactivating spores and yeasts. To increase effectiveness, combined techniques are used, such as the combination of ultrasonication with mild thermal treatment (Aaliya *et al.*, 2021).

Nevertheless, it is important to consider the potential limitations of ultrasound. The formation of free radicals during cavitation could have adverse effects on both the product and the consumer. These effects include the inactivation of important enzymes, denaturation of proteins, and oxidation of fats (Ayodeji Adebo *et al.*, 2020; Taha *et al.*, 2022).

Fermentation can also be considered a suitable way to process *Sambucus nigra* fruit, considering the potential presence of cyanogenic glycosides. It is a non-thermal type of food processing, during which it is possible to significantly reduce the amount of toxic compounds, namely aflatoxins and cyanogens (Jeyakumar & Lawrence, 2022). The hydrolysis of cyanogenic glycosides during fermentation is attributed to the action of enzymes such as  $\beta$ glucosidase, which leads to the reduction of cyanide content (Bolarinwa *et al.*, 2016). Therefore, it can be concluded that fermentation has the potential to reduce cyanogenic glycosides in food products, thereby contributing to improved food safety and nutritional quality.

In addition, the fermentation process determines the changes in the taste and texture of the product. Also, fermentation contributes to the extension of the shelf life of the final product, and fermented products have a beneficial effect on health (Boukid *et al.*, 2023).

# Conclusions

- 1. *Sambucus nigra* fruits are recognized for its high content of anthocyanins, polyphenols, which contribute to its antioxidant properties and potential as a natural colourant in the food industry.
- 2. The bioactive compounds in elderberry, such as

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anthocyanins, flavonols, and phenolic acids, have been linked to various health benefits, including antiviral, anti-inflammatory, and anti-diabetic effects.

- 3. Elderberry extracts have shown potential in reducing cellular oxidative stress and preventing inflammatory processes, and they may be used in developing new pharmaceuticals and functional food ingredients.
- 4. *Sambucus nigra* contains potentially toxic cyanogenic glycosides, especially in the bark, leaves, seeds, and unripe fruits, which can lead to cyanide poisoning.
- 5. Heat treatment of elderberry lectins enhances their susceptibility to enzymatic digestion by pepsin, allowing for effective breakdown during digestion and reducing the risk of potential adverse effects associated with their intact form.
- 6. Thermal processing is commonly used to ensure product safety by reducing microbial and enzyme activity, but it can also reduce the content of beneficial compounds.
- 7. Ultrasonic treatment can reduce cyanogenic glycosides and increase phenolic content.
- 8. Ultrasonic inactivation of microorganisms is a complex process, but it has limitations, such as the potential formation of free radicals.
- 9. Combined methods, such as ultrasonication with mild thermal treatment, can increase efficiency while minimizing negative impacts.
- 10. Fermentation is a non-thermal processing method that can reduce the amount of toxic compounds in *Sambucus nigra* fruits and contribute to food safety and nutritional quality.
- 11. *Sambucus nigra* fruits are a valuable source of bioactive compounds with potential health benefits, but their processing must be carefully managed to balance safety concerns with the preservation of nutritional and sensory qualities. Ultrasonic treatment and fermentation are promising methods for improving the safety and quality of elderberry products.

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# ROSEMARY ESSENTIAL OIL BY HYDRODISTILLATION: SPME-GC-MS CHARACTERIZATION

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#### Abstract

Rosemary (*Salvia rosmarinus*) is an aromatic herb with a multitude of uses. It is both a seasoning in various dishes, and a natural remedy for several diseases mainly due to its anti-inflammatory and anti-oxidative effects. Plus, it is also used in cosmetic industry and for improving agriculture practices and helping the environment, since it may be a natural antimicrobial. It is worth noting that this plant is also grown and commercialized in Uzbekistan, thus, if added value is given to rosemary's products, it has potential for improving living conditions and helping in the economy of local farmers and entrepreneurs. In this work, we discuss a technique for obtaining rosemary essential oil, rich in terpenes, by vacuum assisted hydrodistillation. This is a solventless environmentally friendly and safe technique that allows the obtention of an added value rosemary product where terpenes, compounds responsible for most of rosemary's properties, are the most abundant. Two samples of locally acquired rosemary were sourced, essential oil was extracted, and characterization was then performed by Solid Phase Micro Extraction (SPME) and Gas Chromatography – Mass Spectrometry (GC-MS). As a comparison, a direct injection of a dilution of one of the essential oil samples was also performed. It was concluded that samples of essential oil obtained from both sources were entirely composed of terpenes or terpene derivatives. Besides, SPME was a superior method when compared to direct injection, since a larger number of volatiles was able to be identified.

Key words: Rosemary, Hydrodistillation, Sustainability, Crops, Entrepreneurship, Food Insecurity.

#### Introduction

Rosemary (Salvia rosmarinus, formerly known as Rosmarinus officinalis L.) is a perennial herb native to the Mediterranean region and a member of the mint family Lamiaceae which is closely related to other herbs such as thyme, oregano, and lavender. The name 'Rosemary' derives from the Latin words 'ros' meaning 'dew' and 'marinus' meaning 'sea' - 'dew of the sea'. This name alludes to its natural habitat in coastal areas and is often found near the sea, especially along the sea cliffs of the Mediterranean region. Although it is native to the Mediterranean region and Western Asia, where it has grown wild for thousands of years, it was later spread by humans throughout Europe and other parts of the world, including the Americas, Asia, and Africa (Elyenni et al., 2019; Sasikumar, 2004; Veenstra & Johnson, 2021).

Rosemary has a strong aromatic and sweet smell thus it has a multitude of uses, both as a food additive and otherwise. In cooking, it is used as a seasoning in a variety of dishes such as soups, casseroles, salads, and stews. Its leaves, both fresh and dried, are used in traditional Mediterranean cuisine as a seasoning for meats, fish, vegetables, soups and more. Rosemary dry leaves, flowers, and twigs are used in the processing of fish products. It is added in small amounts to roast meat, roast chicken, minced meat, mushroom salads, vegetable stew and other dishes. In addition to its culinary uses, rosemary is also used for ornamental purposes. In agriculture, rosemary is used as a natural antimicrobial reducing the need for potentially harmful synthetic compounds. It is often used in landscaping, thanks to its resistance to drought, heat, pests, and diseases. Moreover, due to its hardiness and low maintenance, it's a popular plant in xeriscaping, a landscaping method that utilizes water-conserving plants (Sasikumar, 2004; Gonçalves et al., 2022;

Khomidov & Mukumov, 2022). Rosemary has been used in traditional medicine for centuries in various forms, including as a tea, essential oil, and in extracts. In traditional medicine, stomatitis, respiratory diseases, and wounds are treated with decoction made from rosemary. A bath is made from the decoction of rosemary for eczema and other skin diseases, and children are bathed in the decoction (Khomidov & Mukumov, 2022). In folk medicine, it has also been used as a remedy for various diseases including intercostal neuralgia, headaches, migraine, insomnia, stomach-ache, epilepsy, rheumatic pain, spasms, dysmenorrhea, hysteria, depression, and nervous agitation, as well as an antispasmodic, mild analgesic, and for improving memory, physical and mental fatigue, and to cure emotional upset (Ghasemzadeh Rahbardar & Hosseinzadeh, 2020).

Several of those properties have been confirmed in modern studies since rosemary has been confirmed to improve gastrointestinal health by alleviating diseases such as inflammatory bowel disorder (IBD) and colitis. The mechanisms of action involve antioxidant and antiinflammatory properties, as measured through inflammatory biomarkers such as tumor necrosis factor (TNF)-α, interleukin (IL)-1β, IL-6, IL-10, myeloperoxidase (MPO), catalase (CAT), glutathione (GSH), glutathione peroxidase (GPx), malondialdehyde (MDA), and superoxide dismutase (SOD) (Veenstra & Johnson, 2021; Gonçalves et al., 2022). Besides, antimicrobial activity towards C. albicans, P. aeruginosa, E. coli, S. aureus, B. cereus, E. faecalis, V. fluvialis, V. damsel, and S. mutans has been well studied (Veenstra & Johnson, 2021). In general, the major individual components found in rosemary oil, involved in rosemary health improving properties, are 1,8-cineol,  $\alpha$ -pinene, and camphor, among other terpenes (Veenstra & Johnson, 2021; Gonçalves 2022). et al., Moreover,

ethnopharmacological uses including anti-anxiety, antispasm, anti-inflammatory, memory-boosting and analgesic effects of rosemary have been validated by neuropharmacological investigation, thus its potential as a natural treatment for diseases such as Alzheimer's, Parkinson, epilepsy, anxiety, and depression, among others (Ghasemzadeh Rahbardar & Hosseinzadeh, 2020). Another important use of rosemary involves its properties for promoting hair growth. Begum et al. carried a study where after treatment with a herbal hair lotion loaded with rosemary, mice experienced an increase in hair follicle count, hair weight, and hair length (Begum et al., 2023). In another study, in humans, rosemary proved effective for treating androgenetic alopecia (Panahi et al., 2015). Several mechanisms behind rosemary's hair growth promoting properties have been proposed. A stimulation in blood circulation would promote follicles by bringing nutrients and oxygen. Its antioxidant activity would prevent damage in hair follicles by free radicals and improve scalp health. The antimicrobial effect of terpenes within rosemary oil like camphor, cineole and borneol, which have antimicrobial effects, would help control dandruff and fungal infections that can clog follicles and inhibit growth. Besides, its antiinflammatory effect, and its role in inhibiting 5-alpha reductase enzyme, responsible for converting testosterone to Dihydrotestosterone (DHT), especially considering that alopecia is related to high levels of DHT (Dhariwala & Ravikumar, 2019).

The economic importance of rosemary is significant. It is a valuable crop for the essential oil industry, with rosemary oil being a common ingredient in many cosmetic, medicinal, and industrial products. Besides, most of its properties may be attributed to the compounds that conform rosemary's essential oil, especially terpenes. The global market for rosemary extract, primarily used in the food and beverage industry, is also substantial and growing (Ghasemzadeh Rahbardar & Hosseinzadeh, 2020; Veenstra & Johnson, 2021; Gonçalves et al., 2022). In Uzbekistan, rosemary was first introduced by S. N. Kudryashov (1930-36) by growing it in the Botanical Garden of the Central Asian State University (now UzMU). Later, in 1992, Yu. M. Murdakhaev reintroduced rosemary by cultivating it in the Tashkent Botanical Garden as a valuable medical and essential oil plant (Nasriddinova, 2022). Nowadays, rosemary has been successfully grown in our country (Khomidov, Mukumov, & Rasulova, 2023: Nasriddinova, 2022), and nationally manufactured rosemary is sold in Uzbekistan 'Figure 1'.

Hydrodistillation is a relatively simple and costeffective method of essential oil extraction, making it accessible to small-scale producers, thus it is ideal for those local farmers or entrepreneurs who may be interested in producing and commercializing an added value product.



Figure 1. Rosemary manufactured and sold in Uzbekistan.

One of the main advantages of this technique is that it is solvent free, hence no harmful solvents or harsh chemical compounds that may pose health are used; therefore, it is both a safe and an environmentally friendly extraction method compared to solvent-based extraction processes. Vacuum hydrodistillation is a gentle extraction method that, due to a reduced pressure, uses a lower temperature, consequently, it helps preserve delicate compounds in the essential oil, resulting in a high-quality product with a natural aroma (Elyemni *et al.*, 2019).

Solid phase microextraction (SPME) is a sample preparation technique that involves the use of a coated fused silica fiber to extract analytes from samples. The fiber, which is coated with a polymeric stationary phase, is exposed to the headspace above or directly to the sample. The analytes get partitioned between the sample matrix and the fiber coating, reaching an equilibrium. The extracted analytes are then thermally desorbed in the injection port of a gas chromatograph (GC) or high performance liquid chromatograph (HPLC) for separation and detection (Lord & Pawliszyn, 2000). Some key advantages of SPME include being fast, simple to use, solvent-free, and applicable to a wide range of volatile and semi-volatile compounds (Arthur & Pawliszyn, 1990). It provides concentration and clean-up in a single step. SPME fibers are also robust and can be reused many times with minimal carryover between samples. The technique is sensitive, with detection limits in the parts-per-trillion (ppt) range achievable. SPME is especially suitable for on-site or in-field sampling of air, water, and soil due to its small, portable design.

In this work, we disclose a technique for obtaining rosemary essential oil, rich in terpenes, by vacuum assisted hydrodistillation, followed by SPME-GC-MS analysis, and direct injection GC-MS analysis for comparison.

# Materials and Methods

#### Materials

Fresh rosemary was sourced from two vendors in a local market. Samples from each vendor are marked as 'A' and 'B'. There is no especial distinction among vendors or plant material, but we aimed at using two different materials, thus produce two batches of essential oil, and compare the results.

# Hydrodistillation

Extraction by hydrodistillation was based on conditions outlined by Calvo-Gómez *et al.* (2004) (Calvo-Gómez, Morales-López, & López, 2004). A rotary vapor apparatus IKA RV8 with a heating device IKA HB digital (IKA, China) equipped with a recirculating water chiller YHLT-10/30 (Green Distill, China) and a diaphragm vacuum pump KNF N 035.3 AN.18 (KNF, Germany) (13 mbars abs. ultimate vacuum, according to specification sheet) were used.

2 kg of fresh rosemary leaves were ground with 2 L of water for 10 minutes. The mixture was placed in a round bottom flask, connected to the rotary evaporator, which consists of a boiling flask, a condenser, and a receiver flask. The boiling flask was then slowly heated to 85 °C to bring the water and plant material mixture to a gentle boil. The rotating motion of the flask ensures uniform heating and mixing. The rotavapor was connected to the vacuum pump, which was then turned on, what allowed the mixture to be heated to the boiling point of the essential oil components at a lower temperature due to decreased vapor pressure. Cold water at 4 °C was recirculating. Rotary evaporator speed was set at 110 rpm, and pressure at 200 mmHg.

As the mixture is heated, the volatile essential oil components are extracted from the plant material and evaporate. The vapor travels up the distillation arm and condenses in the cold collection flask. Non-volatile compounds remain in the aqueous solution in the round-bottom flask. Once the hydrodistillation is complete, in 3 hours, the rosemary essential oil can be separated from the aqueous layer. The oil contains the aromatic compounds that were isolated through the simultaneous actions of heat, reduced pressure, and fluid rotation in the rotavapor.

#### Analysis

Both Solid Phase Microextraction (SPME) and Gas Chromatography – Mass Spectrometry conditions were based on conditions outlined by Calvo-Gómez *et al.*, 2004 (Calvo-Gómez, Morales-López, & López, 2004) with modifications.

SPME holder and the fibers: Divinylbenzene/ Carboxen/ Polydimethylsiloxane (DVB/CAR/PDMS) 50/30 µm and PDMS (Polydimethylsiloxane) 100 µm were sourced from Sigma-Aldrich (USA).

For SPME, procedure was as follows: 10  $\mu$ L of essential oil were placed in a 4 mL vial, sealed tightly with a screw-top septum-containing cap, and allowed to stand at 30 °C for 1 h. The SPME needle was then inserted through the septum, the holder was secured,

and the fiber was exposed to the headspace. After 30 min of sampling at 30 °C, the fiber was retracted and immediately inserted into the inlet of a GC for thermal desorption. Injection was accomplished by desorption of the fiber for 1 min at 220 °C. Analyses were performed by triplicate.

For GC-MS, analyses were carried on an Agilent 7890/5977 GC-MS (Agilent, USA) using a capillary column HP-FFAP (30m×0.25 mm i.d., film thickness 0.25 µm; Agilent, USA). Conditions were as follows: GC injector was at 230 °C in splitless mode, column temperature was held at 50 °C for 3 min and then increased at 5 °C/min to 220 °C and held for 16 min (for cleaning the column and the fiber); helium was used as carrier gas at a linear flow of 2 mL min<sup>-1</sup>. Mass spectra were obtained at 70 eV, the ion source was at 230 °C, and quadrupole of the MS operated at 150 °C. Data was recorded on SCAN mode m/z 50-550) and the identification of the analyzed compounds was accomplished by comparing their mass spectra with those of authentic compounds available from computerized spectral database (NIST/EPA/NIH).

For comparing SPME with direct injection, using similar conditions as those described above for GC-MS, a single direct injection of 'B' rosemary essential oil was also performed. In this case, essential oil was dissolved in dichloromethane (1:50), and 1  $\mu$ L of this mixture was injected directly into the GC-MS.

For data processing, raw GC-MS data was processed using MSD Chemstation Software ver. F01.01.2317 (Agilent, USA), and Automated Mass-Spectral Deconvolution and Identification System (AMDIS) by Steven Stein, Oleg Toropov, and Andrei Roumiantsev, ver. 2.73, build 149.31. Further data processing and tabulation was performed using MS Excel from Microsoft 365 (Microsoft, USA).

For statistics, One-Way Analysis of Variance (ANOVA) and Tukey's Honestly Significant Difference (HSD) test were performed. Differences between groups were considered significant at a 95% confidence level (p < 0.05). Statistical analyses were performed in Minitab 21.64 (Minitab LLC, USA), and astatsa.com by Navendu Vasavada (last accessed, May 10, 2024).

#### **Results and Discussion**

Rosemary essential oil obtained by hydrodistillation is a yellowish clear liquid. After analysis by SPME-GC-MS with both fibers, DVB/CAR/PDMS 50/30 fiber had a better affinity for compounds in the essential oil than PDMS 100 fiber. 'Figure 2' is a graphic representation of the total number of compounds (8 vs 20 respectively) identified in the chromatogram of rosemary essential oil when sampled by SPME using either PDMS 100 or DVB/CAR/PDMS 50/30 fibers, as well as the total area under the curve of each chromatogram (1.1 x  $10^8$  vs 1.67 x  $10^9$  respectively). Figure 3 is a representation of overlayed chromatograms obtained using both fibers. As it is observed in 'Figures 2' and 'Figure 3', both the abundances and number of compounds is much higher with the DVB/CAR/PDMS 50/30 fiber. Therefore, results in Table 1 for SPME GC-MS analysis of rosemary essential oil are reported from analyzing chromatograms of samples extracted by SPME with the DVB/CAR/PDMS 50/30 fiber. Results are displayed in percentage of total chromatogram area, and Coefficient of Variation (C.V.) is also indicated for SPME analyses (not for direct injection because only one repetition was performed in that case).



# Figure 2. Comparison between PDMS 100 and DVB/CAR/PDMS 50/30 SPME fibers.



Figure 3. Overlayed chromatograms of rosemary oil by SPME-GC-MS with two different fibers.

Twenty compounds were identified in both samples. It is worth noting that all the compounds identified in rosemary essential oil are terpenes (except for endo borneol, which is an oxygenated terpene derivative). Those results are in accordance with previous studies (Al-Shaar *et al.*, 2017; Elyemni *et al.*, 2019; Veenstra & Johnson, 2021; Gonçalves *et al.*, 2022). Besides, as it was mentioned in the introduction section, those compounds have been identified as responsible for several of the medicinal properties attributed to rosemary.

Regarding comparison between both rosemary vendors, A and B, results did not show any statistically significant difference between them since p-values were >0.05 (p=0.9991 in One-way ANOVA, and p= 0.8999947 in Tukey's HSD test). As expected, there are some differences that may be attributed to cultural practices, cultivars, or handling of herbal material. Some compounds, especially some of the most abundant such as eucalyptol,  $\beta$  myrcene, camphor, (+)-4-carene,  $\alpha$  terpinolene, linalool, and D-verbenone, are in similar percentages in both samples. It is worth mentioning that only partial quantification is provided in this study, since relative amounts are based on area percentages and not in calibration curves. However, it is still possible to establish an estimate volatile profile of rosemary essential oil from both samples.

When comparing DVB/CAR/PDMS 50/30 SPME-GC-MS of the B sample vs the direct injection of the same sample, the number of compounds in SPME-GC-MS is 4 times greater than in direct injection (20 vs 5). This shows that SPME is able to detect more compounds present in a sample compared to direct injection alone. The SPME fiber acts as a concentrator and extractor, allowing it to capture more analytes from the sample that might otherwise be missed by direct injection. However, it must be taken into account that concentrations and proportions of individual compounds may be different after SPME extraction (as in the case of eucalyptol and camphor, as shown in Table 1), since affinity for the polymer in the fiber may be different (Arthur & Pawliszyn, 1990; Lord & Pawliszyn, 2000; Al-Khshemawee et al., 2018). Nevertheless, SPME provides an advantage over direct injection in being able to detect and quantify a greater number of compounds in a given sample.

Table 1

		VENI	VENDOR A		VENDOR B		
RT (min)	Compound	SPME (%)	C.V. SPME	<b>SPME (%)</b>	C.V. SPME	Direct (%)	
			(%)		(%)		
1.737	α Pinene	15.51	3.11	10.77	2.73		
2.186	Camphene	7.53	3.34	4.81	3.15		
2.761	β Pinene	3.30	2.67	4.51	2.28		
4.22	cis-Sabinene	1.46	6.81	4.48	8.09	2.02	
4.364	Beta Myrcene	10.81	0.99	10.27	0.71		
4.53	(+)-4-Carene	1.67	0.32	1.62	0.38		
5.203	D-Limonene	4.40	1.91	3.47	2.27		
5.572	Eucalyptol	13.96	0.44	14.82	0.43	45.45	

Compounds in rosemary essential oil (in percentage of total chromatogram area) and C.V.

Continuation of the Table 1

#### ROSEMARY ESSENTIAL OIL BY HYDRODISTILLATION: SPME-GC-MS CHARACTERIZATION

6.188	Trans β	1.46	8.12	3.71	5.96	
	Ocimene					
6.243	γ Terpinene	1.66	3.42	2.49	3.53	
6.674	p-Cymene	5.30	6.37	1.93	8.47	3.03
6.794	β Terpinolene	1.41	1.64	1.54	1.76	
10.069	Camphor	19.15	0.67	19.74	0.33	47.47
10.501	Linalool	1.36	1.68	1.59	1.97	
10.862	Caryophyllene	3.83	4.30	7.06	4.72	
11.473	Terpinen-4-ol	1.11	3.36	1.33	2.12	
12.177	Humulene	0.81	0.77	1.19	0.41	
13.424	endo-Borneol	2.96	4.43	1.67	3.56	
13.493	β Terpineol	1.40	2.78	2.14	3.51	2.02
13.894	D-Verbenone	0.93	2.31	0.84	2.06	

# Conclusions

- 1. Hydrodistillation of rosemary (*Salvia rosmarinus*) yields essential oil full of potentially pharma-cologically important compounds.
- 2. SPME-GC-MS allowed the characterization of rosemary essential oilwhich may bring added value for farmers and entrepreneurs looking for added value in rosemary's products.
- 3. SPME was superior to direct injection for the analysis of rosemary essential oil volatiles.

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# CHEMOMETRICS AS AN AID TO QUICKLY EVALUATE GALACTOMANNANS THROUGH INFRARED SPECTROSCOPY

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# Abstract

Galactomannans, composed of galactose and mannose, may form gels and are considered safe because of their non-toxic, biodegradable, and biocompatible nature. As a result, they are widely utilized in the food industry as stabilizers and thickeners. Among galactomannan producing species, guar gum and locust bean gum are particularly important due to their economical relevance. Guar gum and locust bean gum are often adulterated with cellulose gums like xanthan gum and carboxymethyl cellulose (CMC). Adulteration of galactomannans with other gums may introduce uncertainties regarding functionality and complicate quality control, posing a potential problem for the food industry. Among the different techniques which have been used for determining and characterizing galactomannans, Fourier Transform Infrared Spectroscopy stands out. Especially when coupled to Attenuated Total Reflection (ATR), analyses are performed rapidly, with a minimum sample preparation, and without the need for solvent or previous extraction mechanisms. However, food is a very complex matrix that contains a high number of components which generate a multitude of spectral information and large data sets. Consequently, additional data processing tools such as chemometrics are needed to be able to draw useful information from spectra. Our goal in this work is to show how to optimize conditions for instrumental analysis by infrared spectroscopy of galactomannans and its constituent monomers and create a chemometric model where galactomannans could be differentiated as a single group. We successfully optimized the PCA model obtained after chemometric processing of infrared data through reducing dimensions by loadings selection.

Key words: ATR-FTIR, Chemometrics, Galactomannans, Crops, Food Supply.

# Introduction

Galactomannans are polysaccharides made of galactose and mannose in a structure with a backbone of (1->4)-linked  $\beta$ -D-mannopyranosyl units with side chains of (1->6)-linked  $\alpha$ -D-galactopyranosyl units. They form viscous solutions in aqueous media (gels), thus having been extensively used in food industry mainly as thickeners and stabilizers. Galactomannans naturally occur in various plant seeds (mostly from leguminosae family), although they may occur in fungal species as well (Srivastava & Kapoor, 2005). Among galactomannan producing species, guar gum (from Cyamopsis tetragonoloba) and locust bean gum (from Ceratonia siliqua, also called carob) are particularly important due to their economical relevance (Prado et al., 2005; Dakia et al., 2008). Although galactomannans may have varying physicochemical properties depending on the galactose: mannose ratio, they are in general regarded as safe due to nontoxicity, biodegradability, and biocompatibility (Sharma, Kumar, & Sharma, 2020). Guar gum and locust bean gum are often adulterated with cellulose gums like xanthan gum and carboxymethyl cellulose (CMC) in the food industry, which are generally cheaper thickeners and stabilizers (Prado et al., 2005). However, this adulteration can cause problems. Blends of these gums were found to have varying effects on the flow properties of emulsions, with interactions between the different polysaccharides affecting stability (Nor Hayati, Wai Ching, & Rozaini, 2016). Furthermore, molecular interactions between xanthan gums and galactomannans like guar gum can complicate characterization of such mixtures (Schreiber et al., 2020). Therefore, adulteration of galactomannans with other gums may introduce uncertainties regarding

functionality and complicate quality control, posing a potential problem for the food industry (Flurer, 2000). Various analytical methods have been used to detect adulteration in galactomannans. Some of them are specific for determining galactomannans/ cellulose gels/ mixed systems' properties, like the one developed by Fernandes, where periodate oxidation is used (Fernandes, 1994). And some others are based in widely used techniques such as infrared spectroscopy (Prado et al., 2005). In general, mid-infrared spectroscopy (IR) is a rapid and simple technique which has been shown to be a valuable tool for determining adulteration and authenticity of various foods, including galactomannans. Mendes and Duarte identified intense absorption bands in the region between 950 and 700 cm<sup>-1</sup> which were able to correlate to the presence of adulterants such as starch, different to the polysaccharides which normally exist in coffee, where galactomanans are included (Mendes & Duarte, 2021). Prado et al. used Fourier Transform Infrared Spectroscopy (FTIR) to differentiate among different type of carbohydrate gums and mixtures, including galactomannans (Prado et al., 2005).

In Fourier Transform Infrared Spectroscopy (FTIR), molecules absorb infrared radiation due to changes in the dipole moment of chemical bonds, thus the wavelengths of the absorbed light will depend on the structure of their functional groups; in this manner, individual bands may be linked to specific functional groups. Therefore, structural information from the molecules is gathered and displayed in the infrared spectrum of a compound or mixture of compounds. An important advantage of FTIR, especially when coupled to Attenuated Total Reflection (ATR), is that many different compounds may be analyzed including liquids, powders, polymers, or semisolids. Besides, those analyses are performed rapidly, with a minimum sample preparation, and without the need for solvent or previous extraction mechanisms (Smith, 2018; Tiernan, Byrne, & Kazarian, 2020).

However, food is a very complex matrix that contains a high number of components which give rise to a multitude of spectral information and large data sets. Consequently, fast statistic and mathematical analyses are needed to fully understand all the complexity of data, as well as to be able to draw useful information from it (Roberts & Cozzolino, 2016). Therefore, chemometrics, which may be defined as 'the chemical discipline that uses mathematical and statistical methods, (a) to design or select optimal measurement procedures and experiments, and (b) to provide maximum chemical information by analyzing chemical data' is an invaluable tool that allows for gathering information which is not normally visible in a group of spectra of different compounds, where contribution from many different functional groups from many compounds may cause overlapping to occur (Otto, 2016).

Infrared spectra are obtained after sampling radiation absorption through wavelengths that correspond to the mid-infrared section of the electromagnetic spectrum (4000-400 cm<sup>-1</sup> approximately). Consequently, there are several variables because each sampled wavelength constitutes one. Accordingly, in a spectrum with 2300 wavelengths, there are 2300 variables. For optimizing a chemometric model for IR spectra, variable selection is important for reducing dimensionality and complexity, thus improving model performance and interpretability. Some wavelength regions may contain mostly noise with little chemical information, hence removing these regions improves the signal-to-noise ratio. By selecting characteristic wavelengths or wavelength intervals, the interpretability of the model can be strengthened. Moreover, the wavelengths selected provide insight into the molecular or atomic transitions that are most influential for a given analytical problem. This may aid in chemical interpretation (Yun, 2022). Advantages of reducing dimensionality include reduced risk of overfitting, better model interpretability, and reduced computational cost and time (Lee, Liong, & Jemain, 2018).

A supervised algorithm in chemometrics is a classification or regression method that learns from example inputs in a training dataset that contain labels in order to predict the target labels of new unseen instances. Common supervised algorithms include partial least squares regression (PLS) and linear discriminant analysis (LDA), which have been used extensively in quantitative and qualitative analysis of spectroscopic and chromatographic data. In contrast, an unsupervised algorithm in chemometrics is an exploratory technique that groups or segments a dataset without using labels in order to discover hidden patterns in the data. Examples of unsupervised algorithms are principal component analysis (PCA), cluster analysis, and self-organizing maps (SOM), which have found applications in areas such as process monitoring and fingerprinting to detect outliers or identify new classes. Unsupervised algorithms are generally used for pattern recognition and dimension reduction without prior knowledge of the desired outputs (Wold, Sjöström, & Eriksson, 2001; Geladi, 2003).

PCA is a non-supervised algorithm which may be used to reduce the dimensionality of large data sets by transforming a number of correlated variables into a smaller number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. Loadings represent the correlation between each original variable and the components and can be used to interpret the underlying structure of the components. The loadings identify which original variables contribute most strongly to each component. Variables with high loadings, either positive or negative, on a component are the ones most represented by that component. Therefore, the loadings aid in dimensionality reduction in PCA by identifying which original variables have the strongest influence on the principal components and which variables can potentially be excluded from further analysis without much loss of information (Abdi & Williams, 2010; Jolliffe & Cadima, 2016).

Our goal in this work is to show how to optimize conditions for instrumental analysis by infrared spectroscopy of galactomannans and its constituent monomers and create a chemometric model where galactomannans could be differentiated as a single group. Although papers previously published have reported algorithms for discriminating between different types of galactomannans after FTIR-chemometric analyses (Prado et al., 2005), we are aiming to develop a quick and simple method for discerning galactomannans as a group, while using their individual monomers, mannose and galactose, as reference materials for establishing the model. We also wanted to use an unsupervised algorithm for doing so, to eliminate the requirement of preassigning classifications to specific categories during data processing. Optimization of the model was done through dimensionality reduction following purely chemometric criteria such as loadings associated to wavelengths. We do not claim that this work would be a stand-alone test but rather a supportive material for helping in the development of a tool for a quick identification of adulterants in galactomannans used as food additives.

#### Materials and Methods

Materials: 8 samples of guar gum (from *Cyamopsis tetragonoloba*) (identified in this work as GUA) and 7 samples of carob -locust bean gum- (from *Ceratonia siliqua*) (identified in this work as ALG -for 'algarrobo', carob in Spanish-) were purchased from local producers. Mannose (MAN) and galactose (GAL) standards were sourced from Sigma-Aldrich (USA).

*Equipment:* Agilent Cary 660 Fourier Transform Infrared Spectrophotometer (Agilent, USA) equipped

with a Pike Technologies germanium crystal ATR (Pike Technologies, USA).

*Software:* Resolutions Pro (Agilent, USA), Spectragryph (Friedrich Menges Software-Entwicklung, Germany), MS Excel from Microsoft 365 (Microsoft, USA), Pirouette (Infometrix, USA) and JMP Pro (SAS Institute, USA).

*Methods:* Both guar gum and carob are powders thus the process for instrumental analysis had to be optimized. Since ATR works by sending an evanescent wave into the sample, only that infinitesimal part of the sample that comes into contact with the crystal, specifically within the distance where the evanescent wave penetrates into the sample, will actually provide information regarding absorption of infrared light by the different functional groups found there. Hence, in the infrared spectrum will only be information of that part of the sample, whose specific depth will depend on the crystal of the ATR (because evanescent waves depend on the type of crystal) (Smith, 2018; Tiernan, Byrne, & Kazarian, 2020). Beyond it, any additional sample will be neglected, therefore, a specific weight of sample is not the appropriate way for guaranteeing a proper data acquisition during instrumental analysis.

It is important to guarantee that the part of sample in contact with the evanescent wave is optimized. Thus, before analysis, several parameters were optimized. Since samples are solid powders, different laboratory spoons were used for optimizing sample size. The use of the included clamp accessory of the ATR was evaluated, and finally, the amount of time after placing the sample in the crystal was also considered (since samples may be hygroscopic). Also, cleaning protocols were assessed.

Our final conditions were, regarding the amount of sample, to take about 20 mg of sample (or standard), place them on top of the ATR crystal, and then, using a cardboard aid (not a metallic spatula to prevent damaging the crystal), accommodate it while ensuring that no part of it remain uncovered. We realized that, considering the hygroscopicity of some of the samples, the time elapsed since their placement in the crystal and the time when the readings were performed could bring some changes in the spectra. We also realized that pressing the sample with the clamp accessory of the ATR improved the consistency of obtained spectra. Therefore, we concluded that readings should be taken immediately after securing the swivel pressure tower of the clamp accessory. Additional conditions included the removal of dust and cleaning of both the crystal and plate of the ATR with isopropyl alcohol, while allowing one minute afterwards in order to allow for alcohol evaporation, and to take background reading between samples. Each sample was read 32 times (32 scans) from 750 to 3700 cm<sup>-1</sup> and a wavenumber distance of 4 cm<sup>-1</sup> and resulting spectra provided the data to be used for the assembly of the sample matrices to be processed by the chemometric algorithms that followed.

#### **Results and Discussion**

In this work, we performed ATR-FTIR analyses of several samples of two different types of galactomannans, locust beam gum (carob) and guar gum, as well as of their constituents, monosaccharides mannose and galactose (8 times each). Spectra of all the analyzed samples and standards are displayed in 'Figure 1'. It is worth noting that color coding in the Figure 1 were used for all spectra of the corresponding type of either sample or standard, thus within MAN there are spectra of 8 analyses, as well as in the case of GAL and GUA. In ALG, spectra are of 7 analyses.



Figure 1. Raw infrared spectra of all the samples analyzed in this work (in absorbance).

Since we analyzed both galactomannans and galactose and mannose standards, one conceivable approach to the identification of galactomannans from possible adulterants was to focus on absorption bands present in both samples and standards. However, infrared spectra may have contributions from many sources including fundamental bands, overtones, and possible presence of groups with overlapping absorption bands; therefore, simple interpretation of infrared spectra from complex mixtures may become difficult, as depicted in 'Figure 1'. Therefore, we decided to conduct chemometric analyses to differentiate and analyze the data effectively. By utilizing these analytical techniques, we can uncover meaningful insights and obtain useful information.

Raw spectra contained 2309 wavelengths (thus variables). Although explored, no spectra preprocessing (such as Savitsky–Golay smoothing, first or second derivative, normalization, or rubber band correction) other that background subtraction was performed on the spectra. Therefore, raw absorbance data was the information considered for chemometrics in this study. After assembling the data matrix, dimensions were reduced considering not functional groups nor regions but merely chemometric criteria, in this case loadings.

As explained in introduction, supervised algorithms require pre-assignment to a given category. If we are developing a method aiming for a further detection of adulterants, we do not want to bias the model by assigning any beforehand label. For this reason, an unsupervised algorithm was used to determine dispersion, in this case, Principal Component Analysis (PCA). 'Figure 2' shows the 2D PCA of the complete spectra, with all the wavelengths (a total of 2309) obtained by analysis in the ATR-FTIR equipment.



Figure 2. PCA of raw infrared spectra of all analyzed samples and standards (2309 variables).

Although clear groupings between the samples are noticeable at first glance, there is also a certain dispersion among the different repetitions in both standards, especially in the case of MAN. This dispersion could be related to moisture absorption, as during the optimization process, visible changes in the spectra were observed over time after being placed onto the ATR platform. However, this dispersion only affected some wavelengths, which is why dimension reduction was sought to decrease the dispersion among the different repetitions of both standards (and thus eliminate possible interferences from elements not part of the standards). Besides, GUA and ALG, although very close together, still may be distinguished as two different groups.



Figure 3. Loadings of PCA of raw infrared spectra of all analyzed samples and standards (2309 variables). For improving the model, the analysis of the 'loadings' was carried out. Loadings reflect the contribution that each specific variable (in this case, each wavelength) makes to the system's dispersion, as manifested in the absolute value they have for each principal component. The higher this value, meaning further

from zero, the greater the contribution of that variable to the system's dispersion. In 'Figure 3', the graphical representation of all the loadings in the PCA model depicted in 'Figure 2' is displayed. The 2309 variables are included in 'Figure 3'. Those farther away from the center account for the higher dispersion, while those in the very center bring the least contribution to dispersion. Thus, the first step to dimension reduction involves identifying and gradually removing variables with the lowest contributions according to the loadings. 'Figure 4' is the graphic representation of loadings after said modification.



Figure 4. Loadings of PCA of raw infrared spectra of all analyzed samples and standards after removing wavelengths with minimum contribution to dispersion.

For further optimization of the model, we used supervised algorithms such as K-Nearest Neighbor (KNN), Soft independent modelling of class analogies (SIMCA), Alternate least squares (ALS), and Partial least squares – Discriminant analysis (PLS-DA) in order to identify those wavelengths that account for maximum separation into categories. However, it is important to note that supervised algorithms were used not as the final model but as an aid for wavelength selection for improving the PCA model. In 'Figure 5', the KNN of the spectra is analyzed.



Figure 5. KNN of raw infrared spectra of all analyzed samples and standards.

Ultimately, a new matrix remains where separation between members of the same set will be minimized, while separation between different sets will be maximized. 'Figure 6' represents the PCA created with this matrix, now with only 888 variables.



Figure 6. PCA of dimensionality-reduced infrared spectra of all analyzed samples and standards (888 variables).

Comparing 'Figure 2' with 'Figure 6', it is noticeable how the groups of both MAN and GAL 'compressed'

after the variable reduction by 'distillation' of loadings. Likewise, the groups of both GUA and ALG also compressed and even overlapped, thus now constituting a single set, as originally intended.

#### Conclusions

- 1. ATR-FTIR followed by chemometrics is an excellent technique for analyzing galactomannans that are used as stabilizers and thickeners in the food industry.
- 2. Without chemometrics, useful information which may be obtained from infrared spectra of samples is limited.
- 3. An unsupervised chemometric model, PCA, was successfully optimized through reducing dimensions by loadings selection.

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# IDENTIFICATION OF THE TRACE AND TOXIC ELEMENTS OF WHEAT CULTIVATED IN DIFFERENT REGIONS OF UZBEKISTAN

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# Abstract

In Uzbekistan, the main food product is bread, which is produced in various forms from local and imported wheat. Most of it is not studied by microelement analysis. The objective of this study is to quantify trace elements in locally produced wheat from various cultivated regions of Uzbekistan. Four different varieties of wheat are cultivated in Sirdarya, Tashkent region, Kashkadarya and Fergana were selected for analysis. Next, a comparative analysis of the elemental composition like iron, zinc, potassium, calcium etc., in the selected samples were studied. To carry out the above aims, an innovative research method was chosen, which is called improved instrumental neutron activation analysis. This method differs from others in its high accuracy in determining trace elements and its multi-element nature. Using this method, we can understand how insufficient nutrients are in baked goods made from wheat grain grown in Uzbekistan. Based on the results of the study, it can be recommended to enrich the soil with fertilizers high in iron and zinc. As a result, in turn, will have a positive effect on the health of the population, since today there is a shortage of the above listed elements. It was also revealed that the concentration of potassium and calcium in wheat cultivated in Uzbekistan is in a high state than other elements. Using the chosen method, two toxic elements were determined and according to the analysis for toxic elements, all four samples are recommended for consumption, as they do not exceed the permissible level for food safety.

Key words: wheat, elemental analysis, food insecurity, neutron activation method, food supply.

# Introduction

In Uzbekistan, the main food product is bread, which is produced in various forms from local and imported wheat. Most of it is not subject to microelement analysis. The objective of this study is to quantify trace elements in locally produced wheat grain samples from various cultivated regions of Uzbekistan.

Trace elements (TE) are chemical elements that occur in low concentrations in nature (El-Youssi *et al.*, 2023). The source of microelements for grain is soil and water, from which it is extracted through the root system and transferred to vegetative organs. Humanmade activities can notably elevate the levels of trace elements in the environment, ultimately integrating them into the food chain. Heavy trace elements like cadmium, arsenic, lead, and mercury have no beneficial role in biological systems and can adversely affect human health. Consuming contaminated food is a common pathway for these toxic elements to infiltrate the human body.

Rashid Ben Akame and Naima Makhin reviewed data for presence of toxic elements in food products available in Mediterranean countries (El Youssi *et al.*, 2023). To determine trace elements, the instrumental neutron activation analysis (INAA) method was chosen. The results of this work proved the presence of high levels of toxic element contamination in vegetables and fish from some Mediterranean countries (El-Youssi *et al.*, 2023).

In recent years, many authors around the world have reported several studies on the importance of the elemental composition of plant-based foods. The majority of these studies found that essential metals can lead to harmful effects when consumed in elevated amounts, whereas non-essential metals can be detrimental to human health even at minimal concentrations (Messaoudi & Begaa, 2018). Also, a decrease in the intake of essential metals in the human diet can, in turn, cause big problems both for the growing body and for senior people.

Plant foods can make a significant contribution to human nutrition and health as they contain almost all mineral and organic nutrients recognized as essential for human nutrition. Toxic elements are very important for food security and are defined as those that are present in food in quantities that may be potentially hazardous to human health. In turn, the lack of essential metals will negatively affect the vitality of the human body. Recommended Dietary Allowance is defined as intake level of essential nutrients that are considered sufficient to meet the known nutritional requirements of all healthy individuals based on scientific knowledge (Resolution, 1999). In addition, recommended intakes are classified according to the requirements for certain nutrients based on age group (e.g., infants, children, adolescents and adults), gender (male/female), and physiological needs (e.g., pregnancy, lactation) (Recommended Dietary Values) (Resolution, 1999).

Commercially available varieties of cereals are an important part of the diet of preschool children, schoolchildren and adults, due to their mineral and vitamin content that meets the dietary needs of these target groups. The presence of impurities such as arsenic and mercury in wheat grains can pose a health hazard to people, especially children, since their bodies are most vulnerable to various toxic substances. Using the recommended dietary allowance (RDA), it is possible to control the intake of essential metals and, in cases of deficiency, make adjustments to the diet (Ghuniem *et al.*, 2020).

In their work, authors determined Co, Cr, Fe, Se and Zn in cassava from several cities in Java using the Nuclear Analytical Technique (NAT). Cassava (Manihot esculenta Crantz) is a major food crop grown in subtropical and tropical regions (Kurniawati et al., 2021). In Indonesia, cassava ranks as the third most significant carbohydrate source following corn and rice. Hence, the researchers deemed it crucial to assess the nutritional content of cassava, focusing on its trace micronutrients that are indispensable for human health and pivotal in human metabolism. Instrumental neutron activation analysis (INAA), as one of the NAT methods, was used in this study due to its accuracy and sensitivity for the determination of trace elements. Counting and elemental measurements were carried out using an HPGe detector. Data analysis quality control was applied using SRM NIST (Standart Reference Materials) 1567a wheat flour and yielded good results with recovery percentages ranging from 94.2 to 113.5%. The concentration range of Co, Cr, Fe, Se and Zn was 0.002-0.098, 0.023-0.158, 1.65-18.9, 0.008-0.228 and 2.06-7.68 mg/kg, respectively (Kurniawati et al., 2021).

Microelement (Co, Cr, Cs, Fe, Sc, Se and Zn) composition of Algerian wheat was studied using instrumental neutron activation analysis (INAA). The results showed that the content of trace elements in the studied samples in the province of El Harrach was within the basic safety level of all analyzed elements recommended by the WHA/FAO, with the exception of Co (Beladel *et al.*, 2022).

For monitoring and assessing the health risk of individual trace elements & heavy metals in wheat, rice and soil samples, a study was carried out to determine eight trace elements: cadmium, copper, cobalt, chromium, zinc, lead, nickel manganese in wheat, rice and soil samples collected from different cities of Punjab (India) (Hamid et al., 2020). The results showed a general tendency for the accumulation of trace elements & heavy metals in the samples in the form of Cd > Cu > Zn > Co > Mn. All wheat samples and nine rice samples exceeded the permissible limit for Cd content. Copper levels were high in eight wheat and rice samples, and Zn levels were high in three wheat and one rice samples. However, only one Multan soil sample exceeded the maximum permissible limit for copper content set by WHO in 2007 and EU 2000. The concentration of manganese and cobalt was within the permissible limits, and Ni, Cr and Pb were not detected in any sample. The health risk index was greater than 1 for Cu, Cd, Co and Mn, indicating a potential health risk to consumers (Hamid et al., 2020).

In the work (Mansouri *et al.*, 2021), zinc levels were measured in scalp hair and nails to identify potential risk factors for breast cancer. Zinc level was analyzed using instrumental neutron activation analysis (INAA). In scalp hair samples, it was found in the range of 119–792  $\mu$ g g<sup>-1</sup> in healthy individuals and in the range of 82–806  $\mu$ g g<sup>-1</sup> in patients.

A research was undertaken to examine the microelement profile of Fe, Zn, Mn, Cr and Co in food

products frequently eaten by the people (Mulyaningsih *et al.*, 2021). Sampling was conducted at four traditional markets located in Pandeglang, Cianjur, Magelang, and Bangkalan. The samples collected encompassed dietary items such as carbohydrates, vegetables, fish, legumes, tofu, and tempeh. Prior to analyzing their trace mineral content, the food samples underwent preparation using neutron activation analysis techniques (Mulyaningsih *et al.*, 2021).

Determination of Fe in food products was performed using instrumental neutron activation analysis (INAA). In this study, iron content of 73 local foods from Mamuju District, West Sulawesi Province was determined. The results showed that green vegetables such as kangkong (Ipomoea Aquatica Forsk), bayam (Amaranthus spp), kemangi (Ocimum citriodorum), daun pakis (Diplazium esculentum), daun katuk (Sauropus androgynous), daun seledri (Apium graveolens), daun singkong (cassava leaves), cesim (Brassica rapa) and buncis (Phaseolus *vulgaris*) have an elemental content of Fe > 100 mg/kg. Kangkung, bayam, and kemangi are green vegetables that are rich in the element Fe, the concentration of Fe in the vegetables is more than 280 mg kg-1. Concentrations of the element Fe in vegetables are higher compared to ones in beef or other protein sources (Yusuf et al., 2019).

# Materials and Methods

*Materials:* To assess the microelement composition, samples were collected from 4 regions, with different geographical, soil, climatic and sea conditions. The selected regions are: Sirdarya, Kashkadarya, Tashkent and Fergana regions.

The wheat variety 'Asr' was selected from Sirdarya, the plant height is 95-105 cm, and it is resistant to lodging. The head is cylindrical, large. Plowing the land was turned to the axis. Potassium and phosphorus fertilizers were added to the soil. During the growing season, wheat was abundantly treated with nitrogen for further accumulation in leaves and stems. Humidity during the wheat growing season was 70-75%. During storage, the temperature was kept no lower than +10 and no higher than +15 degrees, and the humidity of the grain itself was 14%. Harvest was in 2023.

The 'Turon' wheat variety was selected from Kashkadarya. Plowing the land was turned to the axis. Potassium and phosphorus fertilizers were added to the soil. During the growing season, wheat was abundantly treated with nitrogen. Humidity during the wheat growing season was 70-75%. During storage, the temperature was kept no lower than +10 and no higher than +15 degrees, and the humidity of the grain itself was 14%. Harvest was in 2023.

The wheat variety 'Alekseich' was selected from the Tashkent region. The wheat is mid-season, frostresistant. A yield of 40 centners per hectare was obtained. The advantage of the variety should be considered its resistance to many diseases.

It is semi-dwarf, the plant height is 81 cm, and it is highly resistant to lodging. Seeding rate is 5 million

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viable seeds per hectare. Harvest was in 2023. The soil was fertilized with potassium and phosphorus. During the growing season, wheat was abundantly treated with nitrogen and potassium. Humidity during the wheat growing season was 70-75%. During storage, the temperature was kept no lower than +10 and no higher than +15 degrees, and the humidity of the grain itself was 14.2%.

The variety 'Alekseich' was selected from Fergana. Plowing the land was turned to the axis. Potassium and phosphorus fertilizers were added to the soil. During the growing season, wheat was abundantly treated with nitrogen and potassium. Humidity during the wheat growing season was 70-75%. During storage, the temperature was kept no lower than +10 and no higher than +15 degrees, and the humidity of the grain itself was 14.1%. Harvest was in 2023.

*Equipment:* The measuring equipment for instrumental neutron activation analysis consists of a WWR-SM nuclear reactor of the Institute of Nuclear Physics of the Academy of Sciences of Uzbekistan, a semiconductor detector made of pure germanium, and a multichannel pulse analyzer. For the analysis, IAEA international standard samples were used - IAEA-36 Lichen, NIST SRFM 1572-Citrus leaves, produced by the US Institute of Standards and Technology.

*Software*: Gamma spectra measured using a semiconductor germanium detector are processed with the Genie-2000 computer program.

Methods:

Iron, potassium, zinc, calcium and etc. elements concentrations were calculated using instrumental methods of neutron activation analysis. Analytical work to determine the trace element composition of selected wheat samples was carried out in the Ecology and Biotechnology laboratory of the Institute of Nuclear Physics of the Academy of Sciences of the Republic of Uzbekistan (INP AS Uz). The neutron sources were a research atomic reactor of the WWR-SM type at the INP AS Uz. In this study, trace and toxic elements in four wheat varieties cultivated in different regions of Uzbekistan were identified by using instrumental neutron activation analysis (INAA).

The selected samples were dried in a special drying cabinet at a temperature of 60°C to constant weight and hermetically packaged in a plastic bag, then placed in a special aluminum container for irradiation with a neutron flux with a flux density of  $3 \cdot 10^{13}$  neutron cm<sup>-</sup> <sup>2</sup>·s<sup>-1</sup>. Based on the gamma spectrum of radionuclides that are formed in the samples under study during irradiation with a neutron flux, the content of microelements present in these samples was determined. The measurement of the spectra of gamma radiation emitted from the sample under study was carried out using a gamma spectrometer based on a high-resolution semiconductor detector. The concentrations of all elements in wheat were calculated using INAA- in comparison with reference samples. In this study, we used standard (SRM) material for the quality control/QA method of the INAA (Bode & Blaauw, 2011).

#### **Results and Discussion**

The risk associated with the intake of toxic elements from food was assessed by taking into account consumer exposure and threshold values, such as the lower confidence limit of the reference dose and the preliminary tolerable weekly intake established by the resolution of the Cabinet of Ministers of the Republic of Uzbekistan 'On approval of the General Technical Regulations on the Safety of Grain' (Resolution, 1999) food additives, respectively.

Table 1 shows the experimental results on the neutron activation determination of toxic elements: arsenic and mercury and comparison with the permissible levels of these elements in food products (Resolution, 1999).

Table 1

Experimental results on neutron activation determination of toxic elements: arsenic and mercury and comparison with permissible levels of these elements in food products

Indicators	Arsenic, As	Mercury, Hg
'Alekseich' Tashkent region	<0.01 mg/kg	<0.001 mg/kg
'Asr' Sirdarya	<0.01 mg/kg	<0.001 mg/kg
'Turon' Kashkadarya	<0.01 mg/kg	0.0053 mg/kg
'Alekseich' Fergana	<0.01 mg/kg	<0.001 mg/kg
Permissible levels, mg/kg, no more	0.2 mg/kg	0.03 mg/kg

All selected grains were results below the recommended tolerable levels and acceptable guideline values. The results were compared with the maximum permissible rate of daily intake of toxic elements and identified as being below the permissible limits.

Table 2 shows the results of instrumental neutron activation analysis of wheat grain samples.

Table 2 Neutron activation analysis of wheat grain

	541	mpies mg	5/116	
Ele- ments	'Alekseich' Tashkent region	'Asr' Sir- darya	'Turon' Kashka- darya	'Alekseich' Fergana
Cu	3.4	3.9	<1.0	<1.0
Mn	20.6	36.4	37.2	26.5
Na	17.6	17	21	23.8
K	3400	3600	3560	4500
Br	0.59	0.22	0.19	0.27
Ca	390	490	410	470
Zn	24.5	47.9	24.4	29.8
Fe	41.4	44.6	49.9	42.2
Se	< 0.01	0.066	0.047	0.13

Eleven elements were assessed and we found three categories: major, minor, and traces of elements that existed in all samples.

The results of the analysis showed that the concentration of copper in wheat growing in the Tashkent region and Sirdarya is much higher than in the other two samples. And the content of the element manganese is significantly lower in wheat growing in the Tashkent region and Fergana, and the Asr and Turon grains predominate in this element. Sodium concentration values vary slightly among regions.

The potassium content in three wheat samples Asr, Alekseich and Turon almost does not change its value, and the Alekseich wheat variety grown in the Fergana region contains potassium by 27.8% more than the average value of this element than in other regions of Uzbekistan.

Calcium is contained in large quantities in the samples Asr, cultivated in Sirdarya and Alekseich, cultivated in Fergana; regarding samples from the Tashkent region and Kashkadarya, it may be seen that the calcium content is 100 mg kg<sup>-1</sup> less. A very important element for human life, zinc is found in a stable value in the samples of the Tashkent region, Kashkadarya and Fergana, and only the 'Asr' sample from Sirdarya has a double value of zinc. The content of iron and selenium in all samples is almost the same.

Table 2 shows the difference between the values of zinc and iron.

Despite the fact that in the Republic of Uzbekistan flour is enriched with B group vitamins and microelements iron and zinc, there is a deficiency of essential elements. And the lack of essential elements such as iron in the human body can cause growth retardation in children, iron anemia in pregnant women, lactating women and children under two years of age (Ursova, 2015). This information may be useful in preventing growth retardation, especially growth retardation caused by glandular deficiency (Erin Farah et. Aa.). Selenium has a positive impact on psoriasis. Selenium is crucial for safeguarding against free radical damage due to its presence in the glutathione peroxidase enzyme.

In Table 2, a large difference between the two main elements potassium and calcium is displayed. Compared to other elements, they exceed the daily human need for these elements.

Potassium and calcium perform very important functions in the human body. For example, calcium helps in the formation of bones and teeth in young children. And potassium is an auxiliary element of the cardiovascular system.

# Conclusions

- 1. Based on the results in the studied wheat, it was established that the concentration of toxic elements such as arsenic and mercury does not exceed the maximum permissible concentrations prescribed by standards.
- 2. The data obtained in this study complements the database on the microelement composition of grain varieties grown in Uzbekistan and allows for preferred varieties for cultivation. Thus, it is possible to select wheat varieties richer in biological components.
- 3. Based on the experimental results obtained, we can conclude that the Alekseich wheat variety, cultivated in the Tashkent region, is the poorest in microelements such as iron, zinc and calcium. Based on this, it is recommended to use fertilizers containing these elements to compensate the deficiency of these microelements.

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# **BIOCHEMICAL ANALYSIS OF MELON SEEDS: THE ROLE OF WATER-SOLUBLE VITAMINS AND FATTY ACIDS IN NUTRITION**

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# Abstract

Melon seeds have been recognized as a nutritional powerhouse, offering a range of essential vitamins and fatty acids that play a critical role in maintaining and enhancing our health. This study aims to analyze the fatty acid profile and water-soluble vitamins in melon seeds in order to highlight the importance of incorporating melon seeds into our diets, not only as a source of nutrients but also as a means of promoting overall health and well-being. It delves into the rich nutritional profile of melon seeds, underscoring their valuable contribution to a balanced diet. Water soluble vitamins C, PP and B1 were detected in melon seeds in this study. Regarding fatty acid profile, PUFA C 18:2 was the most abundant (35.31%), followed by MUFA C18:1 (25.83%), although other unsaturated and saturated fatty acids were also determined. This comprehensive analysis of melon seeds' nutritional benefits encourages further exploration of their potential in enhancing diet quality and supporting long-term health objectives.

Key words: melon seeds, oil, nutrition, food insecurity.

# Introduction

The demand for high-quality vegetable oils for food and industrial uses has led to an increased focus on the fat and oil industry. The by-products of oilseed processing, notably the meal, are vital for providing protein-rich feed in animal husbandry, emphasizing the significance of oilseeds for oil extraction industries. The production of oilseeds is influenced by the diverse agricultural climate of the producing countries, their biological characteristics, and traditional preferences for certain vegetable oils.

The *Cucumis melo* L. plant, part of the pumpkin family, finds its roots spread across Asia, Europe, and Africa. Recent increases in melon cultivation have highlighted their economic value, although parts of the fruit remain underutilized. The rapid spoilage of melons limits their shelf life, but their unique aroma, characterized by compounds like (Z,Z)-3,6-nonadiene-1-ol and phenylethyl alcohol, adds to their appeal. According to Rolim *et al.* (2018), typically only the flesh and seeds are used, leaving the peel and other parts wasted. However, melons are valued not only for their taste qualities; they are also a source of nutrients such as vitamins, proteins and fats, as noted by Laur and Tian (2011), and Lester (2008).

Melon seeds, as well as those from other plants of the same family, are highly valued for producing both high quality vegetable oils, and high protein products. Thus, they may be suitable for their use as food additives or functional foods. In addition to their nutritional value, melon seeds are known for their medicinal properties, since they are celebrated in traditional medicine for their pain-relieving, anti-inflammatory, and antioxidant properties (Ivanova, 2012). They are a rich source of biologically active compounds, including vitamins A, D, C, K, E, and B group, along with essential minerals like magnesium, sodium, phosphorus, potassium, and calcium, as documented by Ivanova (2012).

The oil extracted from melon seeds is rich in biologically active substances such as tocopherols, phospholipids, and sterols, offering several health benefits. These seeds, often regarded as a by-product, are protein-rich (12.0-35.0%) and glyceride-dense (30.0-50.0%). Thanks to the cold pressing process, melon seed oil is globally produced for its high nutritional value, high in polyunsaturated fatty acids (PUFA) (Petkova & Antova, 2015). Melon seeds have a moisture content of 4.5%, crude protein of 25.0%, ash of 2.4%, crude fat of 25.0%, crude fiber of 23.3%, and carbohydrates of 19.8% (Mirzoev, 2015). Research by Petkova & Antova (2015) has highlighted that melon seeds have a diverse fatty acid profile, including oleic acid (24.8-25.6%) and linoleic acid (51.1-58.5%), in addition to containing sterols, tocopherols, and phospholipids.

The importance of linoleic acid in human physiology is determined by its involvement in the synthesis of arachidonic acid and the formation of phospholipids in cell membranes. Increased consumption of linoleic acid, as recommended by dietary guidelines, may reduce the risk of cardiovascular and other diseases. An international team of researchers, analyzing data from 20 prospective cohort studies conducted in ten countries from 1970 to 2010, covering a total of 366,073 patient-years, found that linoleic acid may have a long-term positive effect on the prevention of type 2 diabetes, while arachidonic acid did not lead to adverse effects (Wu, Marlund, & Imamura, 2017).

According to previous analyses at our laboratory, melon (from Chillaki variety) seed oil primarily comprises palmitic (22.34%), linolenic (35.31%), and oleic acids (25.83%), besides it is also an abundant source of tocopherols, especially the  $\beta+\gamma$ -tocopherols fraction (Israilova *et al.*, 2023). Literature reports, such as those by Perry and co-workers (2009), confirm that melon seed oil is an important vegetable oil resource, extensively utilized in the food industry for creating a variety of products (Perry, Wang, & Lin, 2009).

The aim of this study is to examine the fatty acids profile and water-soluble vitamins with potential nutritional importance in seeds obtained from various melon varieties grown in the Khoresm region of Uzbekistan.

#### **Materials and Methods**

Materials: Melons from different varieties, harvested in the Khorezm region of Uzbekistan in 2023, were locally sourced and selected as raw materials. Seeds were kept in clean, dry, odorless, and pest-free storage conditions, as outlined in the GOST 22391-2015 guidelines.

Melon seeds were purified from organic and mineral impurities and crushed to 65% through a sieve with holes of 2 mm. Oil was obtained by cold pressing according to the methodology specified in (Mirzaxmedov *et al.*, 2023) to a humidity of 6-7%. Samples were taken from the resulting oil for analysis in accordance with the standards listed below. Equipment:

High-Performance Liquid Chromatography (HPLC) Shimadzu LC-20 (Shimadzu, Japan). Detector: diode array UV-Vis. Wavelengths used were 270 nm and 361 nm depending on the vitamin.

Gas Chromatography (GC) Shimadzu GC-2030 (Shimadzu, Japan). Detector: Flame ionization detector (FID). Carrier gas: Nitrogen.

Lab Solutions software ver 5.3 (Shimadzu, Japan) was used for data acquisition in both Shimadzu chromatographs.

Oil press: GEMCO model ZX-130 (GEMCO, China). Methodology:

Fatty acids of extracted oil were analyzed by GC in the laboratory of the Center for Innovation and Pharmacy in Uzbekistan, following standard methods in accordance with AOAC and O'ZDST guidelines: Prior to analysis by GC, fatty acids were transformed into their methylated forms using a derivatization technique. For the fatty acid analysis, the oil underwent hydrolysis with a 10% KOH solution in alcohol. The resulting soap was then acidified with 50% sulfuric acid to separate the fatty acids, which were subsequently extracted using petroleum ether (Miyashita & Takagi, 1986). This extract was filtered, dried, and the fatty acids were methylated with diazomethane before their analysis via gas chromatography. This process enabled the detailed examination of the fatty acid composition in the oil samples (Kostyuchenko & Elagina, 2020).

For the chromatographic analysis of fatty acids, a Restek Stabilwax (Restek, USA) column, 60 m in length and 0.32 mm in diameter, was utilized. The oven temperature was programmed to an initial value of 80°C for 8 minutes, followed by an increase to 130°C, where it remained flat for 10 minutes, and finally, to increase to 180°C in 2 minutes, for a total run time of 22 minutes. The analysis was conducted with a split flow mode of 1/10, and the volume of the sample injected was 1  $\mu$ l. One analysis was performed and regression from a calibration curve of external standards was used for quantification.

Water-soluble vitamins such as vitamin C,  $B_1$  and PP, were analyzed by HPLC and quantified by regression against a calibration curve of external standards.

Melon seed cake was used as the sample material.

To prepare the samples, 1 g of sample was accurately weighed into a 50 ml measuring flask, and 20 ml of deionized water were added before placing it in an ultrasonic bath at room temperature for 10 minutes. Following this, 2 ml of 2 mol  $1^{-1}$  sodium hydroxide solution were added, and resulting solution was mixed in for 10 seconds. Then, 25 ml of a buffer solution were added, and the volume was made up to the flask's mark with deionized water (Israilova *et al.*, 2023). A 0,02 ml aliquot of this solution was then injected into the HPLC for analysis. Area under the curve of peaks at retention times (RT) corresponding to those of standards were considered for quantification. One analysis was performed.

#### **Results and Discussion**

The chromatogram, at two different wavelengths (270 nm on top, and 361 nm on bottom), of water soluble vitamins standards, is shown in 'Figure 1'. Retention times are as follows (in minutes in all instances): vitamin C: 4.07; Vitamin PP: 4.523; vitamin B6: 7.069; vitamin B2: 9.501; vitamin B1: 13.654; and vitamin B12: 8.15.



Figure 1. HPLC chromatogram of water soluble vitamins: C, PP, B1, B2, and B6 (top; read at 270 nm); and B12 (bottom; read at 361 nm).

The chromatogram of fatty acids analysis is shown in 'Figure 2'. Each specific fatty acid is displayed in the figure.

The composition (in percentage) of fatty acids in melon seeds is displayed in Table 1, in a comparison with our previously reported results of oil obtained from Chillaky variety melon seeds (Israilova *et al.*, 2023), and from oil obtained from seeds of three varieties of melon (Honeydew, Dessert 5, and Hybrid 1), as reported by Petkova & Antova (2015). In Figure 3, the percentage of SAT (saturated), MUFA (monounsaturated), and PUFA (poly unsaturated) fatty acids in the oil investigated in this study are displayed.



Figure 2. GC chromatograph of fatty acids profile in melon seeds oil.

According to data in 'Figure 3', the most abundant type of fatty acids are PUFA, which account for a 45% of total fatty acids content in melon seeds oil.



Figure 3. Type of fatty acids in melon seed oil according to saturation status.

According to data in Table 1, the most abundant individual fatty acid both in our study and in all other studies compared there, is linoleic acid (C18:2). As stated by Wu, Marlund, & Imamura (2017), consumption of this fatty acid may contribute to reducing the risk of cardiovascular and other diseases. Therefore, the potential health benefits of melon seed oil may be established. Other abundant fatty acids are oleic acid (C18:1), and palmitic acid (C16:0). Although percentages change, as is expected considering both different varieties, extraction methods, and geographic locations, there are also similitudes regarding the most abundant fatty acids found in melon seeds oil in this study, and those previously reported.

In terms of water-soluble vitamins, our study detected quantifiable concentrations of vitamin C, vitamin B1, and vitamin PP, as shown in Table 2.

Table 1

		Current study		Previously pu	blished studies	
Fatty acid	Type of	Khorezm region	Chillaky <sup>a</sup>	Honeydew <sup>b</sup>	Dessert 5 <sup>b</sup>	Hybrid <sup>b</sup>
	fatty acid	(%)	(%)	(%)	(%)	(x)
C11:0	SAT	0.42				
C12:0	SAT	0.06				
C14:0	SAT	0.16	2.32	0.1	0.1	0.2
C16:0	SAT	22.34	9.76	9.4	12.3	16.4
C16:1	MUFA	0.91		0.1	0.1	0.2
C18:0	SAT	4.48	4.21	6.6	6.1	6.5
C18:1	MUFA	25.83	27.98	25	25.6	24.8
C18:2	PUFA	35.31	42.10	58.5	55.2	51.1
C18:3	PUFA	6.97	1.76		0.1	0.2

#### Fatty acid profile of melon seeds oils from different varieties

Source: a: Israilova et al., 2023; b: Petkova & Antova, 2015.

It is important to mention that, although investigated (as displayed in 'Figure 1') by also analysing corresponding standards, no vitamin B6, B2, or B12 was found in melon seeds. The presence of vitamins C, PP, and the B1 in melon seeds may also contribute to fostering a nutritious diet. Vitamin C acts as a potent antioxidant, safeguarding cells from harm and bolstering the immune system. Vitamin PP is instrumental in metabolic processes, and B complex vitamins are crucial for the smooth functioning of the nervous system and metabolism (Elagina & Pankov, 2020; Elagina & Smirnova, 2019).

Table 2

#### Water soluble vitamin content (in mg $g^{-1}$ ) in melon cake

Title	Results (mg g <sup>-1</sup> )
Vitamin C	0.53
Vitamin B1	0.07
Vitamin PP	0.19

#### Conclusions

- 1. The most abundant type of fatty acids in melon seeds oil are poly unsaturated fatty acids (PUFA), which account for the 45% of total fatty acids.
- 2. The most abundant individual fatty acid in melon seeds is linolenic acid (C18:2) (35.31%), followed

by oleic acid (C18:1) (25.83%), and palmitic acid (C16:0) (22.34%).

3. Out of the investigated water-soluble vitamins, vitamin C, vitamin B1, and vitamin PP were quantified in melon seeds. There was no presence of B6, B2, or B12 vitamins.

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# INCLUSIVE RURAL DEVELOPMENT OF TERRITORIAL COMMUNITIES OF LVIV REGION THROUGH FINANCIAL DECENTRALISATION AND TERRITORIAL MARKETING

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# Abstract

Ensuring inclusive rural development of territorial communities requires a comprehensive study and the use of special methods and tools. To ensure such growth, it is advisable to apply financial decentralisation and territorial marketing. The aim of the study is to determine the level of inclusive rural development of territorial communities of Lviv region. The study is based on the analysis of the budgetary indicators of rural territorial communities of Lviv region, a study of the political, economic and social inclusion of active groups of entities of rural territorial communities of Lviv region. The budgetary indicators of rural territorial communities of Lviv region. The budgetary indicators of rural territorial communities of Lviv region. The budgetary indicators of rural territorial communities of Lviv region and the country. Based on the results of questionnaire surveys of active groups of entities of rural territorial communities of Lviv region, the level of political, economic and social inclusion is determined. The research identified indicators of political, economic and social inclusion that shape the perceptions of active groups of entities on further improvements aimed at enhancing inclusive rural development of territorial communities. The results of the research show that the level of inclusive rural development of territorial communities as an indicator of the efficiency of budgetary funds (financial index of inclusive rural development of territorial communities as an indicator of the efficiency of budgetary funds (financial decentralisation) and meeting the needs of active groups of entities of rural communities (territorial marketing) in Ukraine. **Key words:** rural areas, territorial communities, decentralization, territorial marketing, inclusive development.

# Introduction

The process of amalgamation of territorial communities in Ukraine, which began in 2015, has created the preconditions for sustainable development of new districts, including rural areas. The granting of financial autonomy in the process of decentralisation to the regions of Ukraine has allowed the formation of own financial resources of territorial communities to ensure their development. The availability of relevant resources of territorial communities - natural and climatic, land, raw materials, material, human, etc. - has given a rise to the need for their efficient use, reproduction, and increase, which is possible in line with the goals of sustainable development and inclusion. Each region of Ukraine and territorial communities have received equal opportunities for development, formation of resource potential, and use of financial decentralisation opportunities. Territorial marketing and its principles for the development of new territorial entities have become an important tool for administrative management of territorial communities.

It is important to note that in the context of Russia's full-scale aggression on the territory of Ukraine, a certain number of territorial communities were unable to use financial decentralisation mechanisms to the development of their territories and carry out efficient agricultural production. In this regard, agricultural enterprises were forced to relocate to safer regions of Ukraine, in particular to the western part of the country. Lviv region received the largest number of relocated enterprises, including agricultural enterprises of various forms of ownership and scales of activity. This created additional preconditions for the inclusive development of rural communities. A similar trend was observed in the central part of Ukraine. One of the key criteria for the relocation of agricultural

enterprises to other regions of the country was the ability to carry out agricultural production and the administrative procedures of local governments to create comfortable conditions for business activities. The level of professionalism in administrative management and the willingness to make quick management decisions allowed the western regions of Ukraine to receive the largest number of relocated enterprises. This, in turn, created opportunities for development and strengthened the local potential of agricultural producers, ensuring inclusive rural development. The use of territorial marketing allowed to focus attention on groups of entities that are able to meet the needs for inclusive rural development and use the mechanisms of financial decentralisation.

The scientific literature contains studies on inclusive rural development and the use of financial decentralisation mechanisms in Ukraine. In order to the inclusive development of rural ensure communities, it is proposed to use indicators of population size and density, community area, support for farms, and improvement of rural infrastructure (Prokopa, 2022). Inclusive rural development requires the use of mechanisms for adapting to the behaviour of rural residents, creating appropriate conditions for their livelihoods, access to resources and services, decision-making by rural territorial effective communities, and involvement of rural residents in the development of the territory; it is noted that ensuring inclusive development is a function of state regulation of the national economy (Borodina & Prokopa, 2019). A group of authors believe that financial decentralisation is a factor in the inclusive development of territorial communities, including rural areas, which helps to eliminate the negative consequences associated with unemployment and migration of rural residents, the

quality of social infrastructure (healthcare and education), and the state of the environment (Hickey, Kunal, & Badru, 2015; Pavlikha et al., 2022). Inclusive rural development is closely linked to food security, which requires the formation of adequate food stocks, optimisation of various types of risks in the activities of agricultural producers, support for farmers, access to finance and markets (Kadian, 2016). The active implementation and use of innovations by rural territorial communities contributes to solving similar problems with the rural population and will ensure inclusive development in the future (Habiyaremye, Kruss, & Booyens, 2020). Other authors believe that the rural population of territorial communities is able to influence the processes of decentralisation (financial) and take an active part in decision-making on resource allocation, while ensuring inclusive development (Shvets et al., 2019).

Foreign scientists study these problems through the prism of inclusive financial development in terms of accessibility, convenience and usefulness in order to overcome poverty in rural areas (Yanlin, & Chenyu, 2019). To evaluate the development of inclusive finance in rural areas, the developed system of evaluation indicators (inclusive financial indicators of China) is used to determine the level of development of inclusive finance in rural areas (Takakura, 2022). Digital inclusive finance is aimed at developing agriculture in rural areas. The authors used the Digital Inclusive Finance Index, which is an indicator of the quality of rural agricultural development and indicates regional financial imbalances (Shi et al., 2023). It is proved that the use of innovative models of financing (index insurance) of agriculture by various financial institutions ensures inclusive development (Issahaku et al., 2020). The research also found that the potential of agriculture and rural development is a driving force for inclusive growth and poverty reduction, which is achieved through a balanced policy in the field of economic transformation of the country (Nazeerudin, 2022). Active involvement of small farmers and gradual increase in the number of farms ensures the development of the rural economy and promotes inclusive rural development (Zhu, Chen, & You, 2022). The study examines the relationship between inclusion and innovation processes in the context of territorial rural development and concludes that less innovative rural areas can provide growth in inclusive innovation, taking into account their own cultural heritage (Tartaruga, 2021). The sustainable development of rural communities is ensured through the formation of integration associations of producers in the same sector. This creates synergies in production and marketing and establishes nationwide sales channels. The example of dairy co-operatives proves the effectiveness of such synergies, which contributes to the profitability of the participants and the development of rural communities (Shimokado, 2021).

In our opinion, in the context of the authors' research on inclusive rural development of territorial communities using financial decentralisation and territorial marketing, attention should be paid to the formation of the revenue and expenditure parts of the budget of rural territorial communities and the resource capabilities of territories, the possibilities of a synergistic effect from combining the resources of agricultural enterprises and rural infrastructure entities. This thesis is also supported by the opportunities created in the relatively safe regions of central and western Ukraine, where agricultural enterprises have relocated and may potentially join others, depending on the military situation in the country. The use of territorial marketing to ensure inclusive rural development can solve a number of problems of rural residents, improve the efficiency use of resource potential, attract additional resources (financial), and implement a number of spatial development programmes for rural areas in cooperation with foreign partners and territorial authorities.

# **Materials and Methods**

The methodological basis of the study is the approach proposed by the World Economic Forum to assess the inclusive development index (The Inclusive Development Index, 2018). The information sources used are the results of the decentralisation reform (financial) and statistical information on the performance of territorial communities of Lviv region. The principles of territorial marketing were applied to identify active groups of entities capable of ensuring inclusive rural development.

In order to assess inclusive rural development, it is proposed to calculate an integrated index by areas of activity – political, economic, social, which form the inclusive rural development of territorial communities of Lviv region by sectoral dimension. The determination of individual indices by the spheres of activity of each rural territorial community of Lviv region is carried out using statistical information and a survey of active groups of entities capable of ensuring inclusive development.

We include the following active groups of entities:

- rural residents people living in territorial communities and participating in inclusion;
- agrarian enterprises (registered and relocated) entities in the agricultural sector that operate in the crop or livestock sectors;
- state authorities manage rural territorial communities;
- other entities tourists, foreign investors, donors, grantors, infrastructure that provide additional financial revenues and/or serve rural areas.

Active groups of entities are characterised by taking into account component inclusion, which is manifested in the availability and distribution of goods and services, and the level of their quality.

The value of the integrated index of inclusive rural development of territorial community ranges from 0 to 1, where 1 means full inclusive development, 0 means full extractive development (exclusion).

#### **Results and Discussion**

Lviv region has 73 territorial communities, 7 districts and 1928 settlements, including 18 rural territorial communities (Decentralisation, 2022). Table 1 presents data on rural territorial communities of Lviv region. The table shows that the majority of rural territorial communities are concentrated in Sambir, Stryi, Lviv districts, and only one in Zolochiv and Yavoriv districts of the Lviv region. Each rural territorial community has a different number of settlements, territory area, size and density of the rural population. Zymnovodivska and Sokilnytska rural territorial communities of Lviv region have the highest density of rural population.

Inclusive rural development is influenced by the number of agricultural enterprises 'Figure 1' and farms 'Figure 2' operating in territorial communities of Lviv region. The largest number of agricultural enterprises is located in Lviv district – 54, and 239 farms in Chervonohrad district, which is not a favourable area for agricultural production and has no rural territorial communities, but there is an effective policy of local authorities for the functioning of business entities. Rural territorial communities in Lviv and Stryi districts have 229 and 208 farms respectively, which provide jobs for the rural population.

Inclusive rural development of territorial communities of Lviv region is affected by the growing number of relocated agricultural enterprises. During the period of Russia's full-scale invasion of Ukraine, 28.6% (the highest share) of enterprises in the country were relocated to Lviv region, including 30.2% of agricultural enterprises (Statistics, 2022).

Table 1

Rural territorial communities of Lviv region						
Burgal termiterial community	District	Number of	Territorial area of	Population size		
Rurai ternioriai community	District	settlements	the community, km <sup>2</sup>			
Biskovytska	Sambir	32	215.8	17999		
Grabovetsko-Dulibivska	Stryi	12	152.1	12202		
Davydivska	Lviv	23	226.2	20696		
Dobrosynsko-Magerivska	Lviv	36	233.9	16154		
Zhovtanetska	Lviv	14	150.4	10127		
Zabolotcivska	Zolochiv	19	235.3	6242		
Zymnovodivska	Lviv	5	30.9	19658		
Kozivska	Stryi	24	420.9	11471		
Murovanska	Lviv	5	43.1	9617		
Obroshynska	Lviv	6	49.8	7661		
Pidberiztsivska	Lviv	11	124.1	8203		
Ralivska	Sambir	23	229.3	13061		
Rozvadivska	Stryi	9	107.1	12052		
Sokilnytska	Lviv	3	32.9	8448		
Solonkivska	Lviv	21	174.4	13391		
Strilkivska	Sambir	21	320.4	14349		
Trostyanetska	Stryi	17	187.6	7991		
Shehynivska	Yavoriv	30	265.2	10778		

Source: created by authors based on Decentralization, 2022.



Figure 1. Number of agricultural enterprises in the districts of Lviv region. *Source: created by authors based on Statistics, 2022.* 



Figure 2. Number of farms in the districts of Lviv region. Source: created by authors based on Statistics, 2022.

The timely response of the public administration authorities of rural communities in Lviv region and the development and implementation of relocation programmes for agricultural enterprises from the occupied territories of Ukraine allowed the involvement of the largest number of agricultural enterprises and farms. The main advantages of relocation programmes include: selection of a location and lease of land, assistance with logistics and placement of production facilities of agricultural enterprises, provision of housing for employees and search for new employees, support in sale agricultural products and exports abroad. The advantage of agricultural relocating enterprises rural to communities in Lviv region is the common territories with the Polish border and the possibility of diversifying logistics routes for exporting agricultural products abroad.

To assess the inclusive rural development of territorial communities of Lviv region, we selected 5 rural ter-

ritorial communities from each district – Biskovytska, Rozvadivska, Murovanska, Zabolotcivska, Shegynivska. Each of the selected rural territorial communities of Lviv region has different characteristics in terms of the number of settlements, territorial area, and population size.

The budgetary indicators of individual rural territorial communities of Lviv region within the framework of financial decentralisation are presented in Table 2. The table shows that the budgetary indicators of rural territorial communities of Lviv region in most cases exceed the average for Ukraine and are within the region average. A negative trend is the excess of expenditures over general fund revenues per capita. Only the Murovanska rural territorial community has a surplus, which is due to an increase in budget revenues due to tax revenues. The surplus ensures inclusive rural growth of territorial communities and allows them to meet the needs of rural residents and implement various social projects.

Table 2

		Rural terr	itorial comr	nunities	-		
Indicators	Biskovytska	Rozvadivska	Murovanska	Zabolotcivska	Shegynivska	Average indicator for Lviv region	Average for Ukraine
General fund revenues per capita (UAH)	1840.6	4328.4	10317.9	5370.7	6641.8	3114.1	1145.1
General fund expenditures per capita (UAH)	6455.3	6516.7	8023.7	9623.2	8830.8	4704.8	1750.8
Capital expenditure per capita (UAH)	1768.1	1597.2	5530.8	955.5	1356.0	826.1	74,9
Level of budget subsidisation (%)	47.0	21.2	6.6	12.1	7.6	16.7	15.6
Ratio of expenditures on maintenance of governing bodies to the amount of general fund revenues (%)	56.7	20.9	17.7	21.5	21.4	24.5	28.4
Share of salaries in general fund expenditures (%)	86.2	79.2	76.9	76.3	77.4	80.6	82.5
Expenditures on general secondary education per pupil (UAH)	37619.1	29435.8	36061.1	50444.9	47784.5	23926.4	9364.1
Share of local taxes and fees in general fund revenues (%)	34.6	29.1	40.1	19.9	17.8	31.2	36.6

Budget indicators of selected rural territorial communities of Lviv region, Q4 2021

Source: created by authors based on Decentralization, 2022.

A positive aspect is the significant amount of capital expenditures of rural territorial communities of Lviv region compared to the average, which are intended to implement infrastructure projects and ensure inclusive development. Most rural territorial communities of Lviv region have a low level of subsidisation. Expenditures on the maintenance of governing bodies and the level of labour costs of the governing bodies of rural territorial communities are within the average. The ability to provide education for rural youth is evidenced by the indicator of expenditures on general secondary education per pupil, which is significantly higher than the average and serves as an important factor in the development of human potential in rural territorial communities of Lviv region.

Let us analyse the individual indices of political, economic and social inclusion of rural territorial communities of Lviv region (Table 3). The integrated index of inclusive rural development of territorial communities of Lviv region, taking into account

sectoral dimensions, is presented in 'Figure 3'. The table shows that the highest level of inclusion by sectoral dimensions is observed in the political sphere. All rural territorial communities of Lviv region have the highest rate. This is explained by the accessibility and quality of administrative services, the appropriate level of management decision-making, and the effective use of budget funds within the framework of financial decentralisation. The disadvantage of such inclusion is the budget deficit for financing expenditures in some rural territorial communities of Lviv region (Biskovytska, Rozvadivska, Zabolotcivska, Shegynivska), which can significantly reduce inclusive development. The economic inclusion of rural communities of Lviv region depends on the efficiency of economic activity of agricultural enterprises in the district, accessibility of rural residents to the labour market, and the availability and affordability of economic resources.

Table 3

Sectoral	T 1 .	Rural territorial communities					
dimension	indicators	Biskovytska	Rozvadivska	Murovanska	Zabolotcivska	Shegynivska	
Political inclusion	Accessibility and quality of administrative services	0.74	0.79	0.90	0.85	0.88	
	Level and quality of management decision- making	0.70	0.75	0.92	0.82	0.87	
	Allocation of budget expenditures	0.69	0.71	0.88	0.74	0.81	
Economic inclusion	Efficiency of economic activity	0.71	0.72	0.78	0.70	0.73	
	Accessibility to labour market	0.72	0.68	0.75	0.65	0.69	
	Access to economic resources	0.64	0.65	0.72	0.60	0.63	
Social inclusion	Opportunity to get a quality education	0.83	0.80	0.88	0.92	0.87	
	Availability and quality of social services	0.84	0.82	0.85	0.83	0.81	
	Preserving and developing human potential	0.79	0.77	0.81	0.74	0.65	

Individual indices of inclusion by sectoral dimension of rural territorial communities of Lviv region

Source: authors' research.

The most problematic element of economic inclusion is access to economic resources, which is associated with their limitation and rising costs. Economic inclusion is more favourable in the Biskovytska and Murovanska rural territorial communities of Lviv region. The social inclusion of the studied rural territorial communities of Lviv region is based on the possibility of obtaining quality education, accessibility and quality of social services, preservation and development of human potential – the most important prerequisite for the rural areas development. The accessibility and quality of social services in the rural communities of Lviv region is ensured at a high level. The Shegynivska rural territorial community has a low level of preservation and development of human potential, as it is closest to the border with Poland and there is migration of the rural population to this country.

Integrated index of inclusive rural development of territorial communities of Lviv region is above the average level and ranges from 0.74 to 0.83. Murovanska rural territorial community has the highest level.

Determining an integrated index of inclusive rural development of territorial communities taking into account sectoral dimensions serves as an effective tool for monitoring the implementation of financial decentralisation and meeting the needs of active groups of entities identified through territorial marketing.



Figure 3. Integrated index of inclusive rural development of territorial communities of Lviv region taking into account sectoral dimensions.

Source: built by authors.

#### Conclusions

- 1. Inclusive development of rural territorial communities is considered as a concept of guaranteeing and creating conditions and opportunities for active groups of entities to use economic resources, forming and efficiently using budget funds within the framework of financial decentralisation, and active participation of rural residents in making informed decisions by the territorial community. Inclusive rural development contributes to the preservation of rural human potential, improvement of the welfare of rural residents, enhancement of the quality of social services, and efficient agricultural activities.
- 2. The necessity of using the methodology for assessing the integrated index of inclusive rural development of territorial communities of Lviv region taking into account financial decentralisation and territorial marketing tools is substantiated. Active groups of entities of territorial communities that influence the inclusive rural development of territorial communities (rural residents. agricultural enterprises, public authorities, other entities) are identified.
- 3. Based on the use of data and monitoring of the decentralisation reform, the rural territorial communities of Lviv region, the number of settlements, territorial area of the community, population size, and the number of agricultural enterprises and farms were identified. Based on these data, rural territorial communities were selected for inclusive development assessment.

- 4. Taking into account the process of financial decentralisation, the budgetary indicators of rural territorial communities of Lviv region are assessed. It is established that there is a deficit of financial resources of rural territorial communities, which can negatively affect the implementation of local programmes and reduce inclusive rural development.
- 5. Individual indices of inclusion by sectoral dimension (political, economic, social) of rural territorial communities of Lviv region are determined. The research has shown that the political component has the greatest impact on inclusive rural development. Social inclusion creates conditions for the formation of high-quality human potential of rural residents, its preservation and development. Economic inclusion is ensured by access to resources and the efficiency of their use.
- 6. According to the results of the calculation of integrated index of inclusive rural development, it was found that studied territorial communities of Lviv region have an appropriate level of development that is above average and are able to ensure its growth by increasing budget revenues, implementing socio-economic programmes, improving the quality and accessibility of social services, creating conditions for preserving the human potential of rural residents, attracting agricultural enterprises through relocation from the temporarily occupied territories, creating new jobs.

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# MEASUREMENT OF SUSTAINABLE ENTREPRENEURSHIP – BENEFITS IN A BREEZE: A REVIEW

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# Abstract

When it comes to moving towards sustainable entrepreneurship, a knowledge-based economy is starting to affect companies and how they are managed. It is relevant for researchers and entrepreneurs to evaluate different sustainability aspects and look for ways how to achieve entrepreneurship sustainability. In the past couple of decades, many indicators have been developed which measure the performance of sustainable entrepreneurship. Not all cover a sufficient basis to provide a thorough evaluation, though. The goal of the study was to evaluate the expertise in sustainable entrepreneurship among large companies with metrics identified in the latest scientific literature review. In the process of the literature review, authors identified key metrics to measure the performance of sustainable entrepreneurship and split them into six groups. They mostly focus on social, environmental, and economic performance measurement. Relatively few research results mention the importance of corporate management indicators. Thus, the key metrics are distinctive by including corporate management as a separate aspect in the performance measurement. The conceptual framework is represented by the acronym *BREEZE*, including 6 groups of key metrics: *brand awareness and consumer behaviour, responsibility for society and employees, environmentally friendly materials, ease of use and reuse* (disposal), *zero waste, economic performance* (approbated on focus group discussion and expert interviews). The results revealed that the expertise levels in sustainable entrepreneurship among the large companies are fair. Complementary data analyses were carried out; as a result, authors developed a self-evaluation matrix in sustainable entrepreneurship.

Key words: circular economy, corporate social responsibility, metrics, measurement, sustainable entrepreneurship, performance indicators.

#### Introduction

Entrepreneurship, a knowledge-based economy is starting to affect companies, and how they are managed. It is relevant for researchers and entrepreneurs to evaluate different sustainability aspects and look for ways how to achieve entrepreneurship sustainability and how to measure performance.

The Strategy of Latvia for the Achievement of Climate Neutrality by 2050 sets the main goals – reduction of GHG emissions in all economic sectors and increase of CO2 removal. The most actual questions among researchers and entrepreneurs are related to how to build business more sustainable. Also, whether companies by introducing unprecedented elements of sustainability into different business processes and engaging in the circular economy will have better financial performance, for example, profits will increase. In this context sustainable business has various advantages, for example, access to new markets, cost reduction, improving business efficiency and building brand image, excellent reputation, and loyalty (Chungyalpa, 2019).

Sustainable entrepreneurship envisages adhering to the principles of circular economy: recycling, upcycling with a particular focus on sharing economy - reuse, cooperation platforms; corporate social responsibility (CSR) - fair trade, sweatshop-free and use of indigenous materials and production; technological innovation (digital technology, physical technology and biological technology - sustainable raw materials); consumer awareness (proactive engagement, participation in value creation etc.). Sustainable entrepreneurship is essentially the participation of stakeholders in sustainable value creation and decision-making (Liu, 2011: Freudenreich, Lüdeke-Freund, & Schaltegger, 2020). Circular supply chain management means that circular thinking is integrated into supply chain management, involving all stakeholders, namely, product manufacturers, service providers, consumers, and users in a product or service life cycle. Basically, in this management materials are being restored and reused to build a zero-waste vision including business innovations from different interested parties (Farooque et al., 2019; 2022; Gallardo-Vázquez, Herrador-Alcaide, & de la Cruz Sánchez-Domínguez, 2023). The former research results of scientists appear that environmental regulation and waste management policies are very important factors that can influence the driving green business promoters of the circular economy, because they define guidelines that can help their businesses develop sustainable concepts (Mondal, Singh, & Gupta, 2023). However, a complex approach, or the integration of a company's environmental, social, economic, and corporate governance activities, is also essential. A circular economy is based on principles aimed to 1) reduce waste and pollution to a minimum, 2) reuse and recycle products and materials, and 3) restore natural resources. It can be said that circular economy aims to keep products and materials at their highest usefulness and value (Saidani et al., 2019; Benachio, Freitas, & Tavares, 2020). For this reason, companies for a long time have searched for different ways how to measure elements of sustainability, including the various uses of resources that create economic costs and definite emissions and wastes as required by regulation. Nevertheless, this needs analysis and reappraisal of business processes - to identify process every step and how many recourses it uses, how much waste it makes, how many people it includes, and which steps attach (and which don't) value in the context of customer and interested parties' perceptions (Székely & Knirsch, 2005).

In addition to that, most of the literature covers only environmental, social, and/or economic aspects of sustainable entrepreneurship. Though in the context of the UN SDG's, no less of an importance is given to corporate management and its role in running a sustainable business. The significance of the corporate management aspect lies in, first, the strategic decisionmaking process; second, the relation to outcomes in the operational level; third, the access to resource and cooperative abilities. Corporate management may present as a critical driver of sustainable entrepreneurship through deliberate leadership activities (Saeed et al., 2018; Dhir et al., 2023). Meaning, if business activity is a result of coordinated actions, such as implementation of goals, allocation of resources, setting of organizational norms and others, then the performance in sustainability largely depends on the decision-making of the top management (Ali et al., 2022). As a result, any policy will have an impact on the outcomes within the operational level functioning. For example, use of false pretenses in order to gain societal support, recognition, or reputation will severely compromise the overall performance in long term due to the failure in making an impact on the operational level (de Freitas Netto, Sobral, Ribeiro, & da Luz Soares, 2020; Coffay & Bocken, 2023). Lastly, carrying out sustainable entrepreneurship will be coupled with additional administrative burden and obligation to respond to governmental demands and stakeholder needs (Aliabadi, Ataei, & Gholemrezai, 2022; Huang at al., 2023). There is no other functional level of a company that would have the resources to do so; as a result, top management can be considered as highly important factor in carrying out sustainable business activities (Bocken, Boons, & Baldassarre, 2019).

The authors provide the argument that corporate management has advantages to generating most of the potential for success in sustainable entrepreneurship. For example, there is evidence that sustainability values within management may positively regulate the sustainability-related performance of an enterprise (Coffay & Bocken, 2023). For example, employee behavior has been highly associated with the intentions and policy of the upper echelon of a company. In other words, sustainability-orientation within the top management has shown to produce more pronounced awareness and commitment towards environmental and social issues at an operational level (Saeed *et al.*, 2018; Ali *et al.*, 2022). That in turn boosts the overall performance in sustainability of a company.

Sustainable entrepreneurship has also shown to benefit local economies by aiding the economic growth and facilitating the transition to circular economy (Calderon, Carillo, & Contreras, 2020). Whereas the engagement with stakeholders can help to produce targeted strategies that can be applied through various business processes to make meaningful changes in the wellbeing of different societal groups (Mondal, Singh, & Gupta, 2023).

Despite the findings on the numerous benefits of sustainable entrepreneurship, the practical expertise levels among entrepreneurs tend to be low which accounts for the low engagement rates and slow transition towards more sustainable business practices (Huang et al., 2023). As a result, the issue presents a need for a comprehensive measurement system for the performance of sustainable entrepreneurship that can be easily used not only to collect data on the performance but in addition can serve as a great tool to evaluate the expertise levels. Such ability would provide a detailed insight into the specific aspects that a company may be lacking and should be improving or, on the other hand, point out the aspects that the company is performing well in, in which case the focus can be diverted to other no less than important processes of sustainable entrepreneurship.

The main focus of the article is on sustainable entrepreneurship measurement metrics and their implementation in the evaluation of the expertise levels of companies. In the process of literature review, the authors identified the key metrics to measure the performance of sustainable entrepreneurship and split them into six groups - *brand awareness and consumer behaviour, responsibility for society and employees, environmentally friendly materials, ease of use and reuse (disposal), zero waste, economic performance.* The conceptual framework is represented by the acronym *BREEZE*. The metrics were further applied to test the expertise levels in sustainable entrepreneurship large companies and to develop a self-evaluation matrix.

#### Materials and Methods

A monographic research method was used in this research in order to identify metrics for measuring sustainable entrepreneurship. In the process of literature review, articles published in 2004-2024 were used. As a result, 6 groups of key metrics were identified. After summarising the results of the literature review and identifying the key metrics, a focus group discussion (n-9) was conducted to find out the opinions of focus group participants (experts) on the use of metrics (a better understanding of the causes of problems - what challenges and possibilities prevent the implementation of the metrics). The experts selected were industry professionals - retail companies that work on the principle of store chains. The focus group discussion was on 16.11.2023. The focus group topics were selected based on the key indicators for measuring sustainable business performance, identified previously in the process of literature review. The discussion expanded into reflections on the impact on the environment, society, perception of the standard of living, expectations and concerns about the future and the economy. The conversation took place in three stages: the purpose of the metrics, economic and environmental potential, cooperation and implementation challenges and possibilities.

To further validate the metrics, a pilot study was run to observe the expertise levels in sustainable entrepreneurship among large companies. To carry out a qualitative analysis, the authors, accordingly to the BREEZE concept, initially, developed a 50-item questionnaire in Likert scale measuring responses from 1 to 5 (1 - completely disagree, 2 - disagree, 3 - neutral,4 - agree, 5 - completely agree). Then, following a Delphi method (26.02.2024.-15.03.2024.), a group of experts (n-10) – individuals that are holding a leadership position within the middle or top management level of companies that met the size criteria (Company must fill one of two criteria - it either employs at least 249 workers, or annual turnover exceeds 50 mil. eur and the total balance exceeds 43 mil. eur) – were selected to participate the study. The main task was to evaluate the expertise levels in sustainable entrepreneurship through conducting a questionnaire. After obtaining their consent, 10 expert interviews were completed. The participation was confidential and personal data was not collected. After finishing the interviews, the results were collected and analysed.

# **Results and Discussion**

Measuring sustainability is related to the inclusion of economic, environmental, social and governance factors in business activities - it is measured to what extent the aforementioned factors are included in business activities, as well as measuring the impact of business activities on the environment. Many researchers have emphasized that corporate sustainability performance cannot be measured only by economic results. Measurement and evaluation should also include non-financial indicators – intangible assets, relations with employees and customers, as well as other involved parties or stakeholders (Dočekalová & Kocmanová, 2016).

In the past couple of decades, many indicators have been developed which measure the performance of sustainable entrepreneurship (Székely & Knirsch, 2005; Saidani *et al.*, 2019). They mostly focus on social (charity, respect for human rights, health, wellbeing, etc.), environmental (waste volume, energy, consumption of materials and raw materials, etc.) and economic (profit, turnover, costs, investments, etc.) performance measurement (Caeiro *et al.*, 2012; do Paço *et al.*, 2013; Veloutsou *et al.*, 2013; Pislaru, Herghiligiu, & Robu, 2019; Martinez *et al.*, 2020). However, relatively few research results mention corporate management indicators and their connection with customers and stakeholders.

The main factors that developed green innovation initiatives were:

- 1) environmental regulations;
- 2) market demand;
- 3) government pressure;
- 4) competitor pressure;
- 5) corporate social responsibility;

6) employee conduct. In this context the implementation of green innovation initiatives positively influences competitiveness and financial indicators (German *et al.*, 2023).

The company's activities include a focus on the social benefit of stakeholders, which stems from the earlier assumption that these entrepreneurs engage in CSR as an expression of their entrepreneurial spirit. At a theoretical level, their characteristics can be measured along the following dimensions (i.e., constructs): employee care, inclusive work practices, product and service quality, business relationships, energy savings, and reduced corporate environmental impact (i.e., factors), etc. These characteristics can transfer from organizational behavior to broader initiatives in society and stakeholder environment (Veleva, Bodkin, & Todorova, 2017; Gallardo et al., 2023) as well as implement more effective and productive management in context of digitalization (Sergejeva, Mangale, & 2022). Investing resources in the Vergins. development of environmental issues, management, digitalization, socially responsible products and services can help achieve CSR and company profits (Alonso & Austin, 2018). For example, measuring the impact of reusable packaging, both from the point of use and recycling and utilization - performance targets, including reduction of waste, inventory and materials, water and energy use; and maximizing product availability, number of recovery streams and efficient use of supply chain assets (Mesa, Esparragoza, & Maury, 2018; Betts et al., 2022).

Consumers are minded paying more for eco-friendly products and services. Especially Generation Z, because they are very concerned about climate change and environmental sustainability and their values include care for the environment (Yang et al., 2023; Gomes, Lopes, & Nogueira, 2023). Therefore, to reach green objectives businesses need human resources that are motivated for the very same reasons. This can happen, if businesses integrate their green policies into their green shared vision and begin to use socially responsible activities to gain society and stakeholders' attention. Companies can raise awareness through their activities. Enterprises must implement a measurement system in their operations. Waste management is related to such areas as management, marketing, production, sales, etc. (Lanqing, 2011). Measurement indicators can be used at the micro and macro level. Micro-level indicators measure the performance of a product or enterprise, while macrolevel indicators refer to the performance of a set of enterprises or a sector in a region or country. Indicators that can measure a company's performance are classified below (Bilan et al., 2017; Syu et al., 2022; Casno & Sloka, 2023).

#### Focus group discussion

The result of the focus group discussion – reflections on the impact on the environment and society. It was found that not only the organizational processes of the company but also the production and promotion of the products have a significant impact on the result. Primarily, companies should focus on the offered product and the consumer - raw materials, composition, packaging, use, promotion. On the other hand, the perception of the standard of living, the conditions of an inclusive work environment must be considered. Thus, action steps in carrying out activities in the conduct of sustainable entrepreneurship include revision of the company's internal operation, optimizing production - surplus, waste, loss reduction, as well as monitoring the origin and processing of raw materials, improving the working environment, engage in community health improvement, product life cycle analysis and improvement, product certification, as well as informing consumers, browsing recycling options, repeat use, product design and development resulting in more efficient and sustainable product solutions. Finally, regarding the expectations and concerns about the future and the economy, the customer segment (building relationships with customers through marketing and sales activities, engaging in the product life cycle); the capital segment (ensuring transparency, accessibility and cooperation with funding parties); the partner segment (selection of suppliers and partners that comply with the principles of sustainability, ensuring safe cooperation); the employee segment (management of favorable working conditions and remuneration); and the public stakeholders segment (environmental, social and regulatory activities) were identified as the most important areas of influence on the company's operation. Based on the literature review and the results (reflections) of the focus group discussion, the key metrics for measuring sustainable entrepreneurship were identified. They are grouped into 6 groups, represented by the acronym BREEZE (see Table 1).

Table 1

Group	os of metrics	Explanation
В	Brand awareness and consumer behaviour	Measurement of sustainable marketing for consumer behaviour change – brand identification, consumers' response towards the brand, brand equity, brand awareness, proportion of responsible consumers after purchase, etc.
R	Responsibility for society and employees	Measurement of entrepreneurship corporate responsibility – proportion of women (total and top management), proportion of disabled, training expenditure, health, accident and sickness rates, personnel cost (total and per person), average fluctuation and net change in employment, donations and sponsoring, total spending for culture and society, etc.
Ε	Environmentally friendly product packaging materials	Measurement of recycled packaging and biodegradable materials (% of total packaging), etc.
Ε	Ease of use and reuse (disposal)	Measurement of product use – number of reuses, unpacking and separation options, etc.
Ζ	Zero waste (lifestyle)	Measurement of entrepreneurship management (incl. process) – paper, water, energy, waste consumption, business travel, etc. ( <i>tons, m<sup>3</sup>, GWh, kg, CO2 emissions, km</i> ). In addition, can be measured percentage of waste recycled, % of employees in environmental management, etc.
E	Economic performance	Measurement of entrepreneurship economic forces – cash flow, earning before tax, taxes paid to all tax-levying authorities, total spending for culture and society, net profit, sales, profit after tax, subscribed capital, personnel costs (wages, salaries, social welfare contributions, pension plan expenses, employee benefits), revenue, etc.

To measure the benefits of sustainable business, companies can measure immediately, regularly monthly, quarterly per employee or total annually. The results need to be presented in the annual report (balance) for attracting investors' attention.

# Pilot study

The results of the pilot study revealed that the expertise levels in sustainable entrepreneurship among large companies are fair, on average estimated at 72% of completion of the total criteria. The lowest scores were detected in social and corporate management aspects of sustainable entrepreneurship with an average estimated at 70% of completion of the respective criteria. The results indicate limits in the general knowledge about various business processes that are associated with social issues and the impact that the corporate management can have on the sustainability performance of the company (Coffay & Bocken, 2023). The authors concluded that there is an overall good potential for integration of sustainable entrepreneurship model into the current business practices. However, to test the data and the strength of relationships between the variables, the questionnaire should be reviewed and refined, and a large scale study should be carried out to test for the statistical significance of the observed interactions. The additional analysis revealed interesting trends between expertise in sustainability criteria related to the corporate management compared to avapting in

corporate management compared to expertise in sustainability criteria related to environmental, social, and economic aspects that served as a basis to developing a theoretical self-evaluation matrix in sustainable entrepreneurship. In other words, the authors observed a strong positive relationship that was distinctive from other observed relationships between the other aspects of sustainable entrepreneurship. Due to the small sample size, it was not possible to determine the statistical significance, thus the study should be replicated with larger sample sizes.

The matrix consists of four sections where each describes a specific position in expertise levels and points to the potential in carrying out a sustainable entrepreneurship model, see 'Figure 1'.



entrepreneurship.

The bottom left section entails low performance in corporate management and low performance in environmental, social, and economic aspects which indicates an entrepreneurship that is not characteristic to sustainable business. The bottom right section entails high performance in corporate management and low performance in environmental, social, and economic aspects which indicates sustainable entrepreneurship with limits to the operational level. The top left section entails low performance in corporate management and high performance in environmental, social, and economic aspects which indicates an entrepreneurship lacking sustainable executive control. Lastly the top right section entails high performance in corporate management and high performance in environmental, social, and economic aspects which indicates to sustainability-oriented entrepreneurship. Authors also point out that based on the location of the matrix, the potential in transformation to sustainable entrepreneurship varies, increasing in strength in upward diagonal direction across the matrix, see 'Figure 2'.

The present study provides numerous insights into the current understanding of the sustainable entrepreneurship concept and the performance measurement indicators. In addition to that, the results reveal direction for future research.

Other sustainable entrepreneurship measurement indicators need to be studied deeper in future.



Figure 2. Indicator for potential in sustainable entrepreneurship.

Highlighting the issues of social responsibility for health (well-being), the authors continue research in the field of sustainable business measurement. Additionally, it is necessary to validate the matrix in further research by running a large scale quantitative analysis in order to develop practical solutions to facilitate the integration of the measurement system into the present business practices of large companies. Future direction for the present study also includes the metric system's application opportunities to the small and medium enterprises (SMEs) since they account for the majority of all companies. Authors predict that the SMEs will be a subject to sustainability regulations in a near future. Thus, to decrease the administrative burden and raise awareness of sustainable business practices, the discovered BREEZE metrics and selfevaluation matrix should be exclusively adapted to SME performance measurement as well.

As a result of the present research, the theoretical framework was used for a survey of large enterprises in the food industry with the aim of determining the quantitative measuring instruments of business performance and developing a measurement scale. Based on the scientific literature review, the BREEZE framework was developed, including six groups of sustainable entrepreneurship performance metrics. (brand awareness and consumer behaviour, responsibility for society and employees, environmentally friendly materials, ease of use and reuse (disposal), zero waste, economic performance). The metrics were further applied to run a pilot study to evaluate the expertise levels in sustainable entrepreneurship among large companies. As a result, authors identified tendencies, which further served as a basis to the development of a selfevaluation matrix in sustainable entrepreneurship. The matrix allows to determine the potential for the transformation to sustainable entrepreneurship model and to identify the key aspects following the BREEZE conceptual framework that may have to be advanced to reach a higher potential.

# Conclusions

1. Sustainable entrepreneurship envisages adhering to the principles of circular economy, including the

participation of stakeholders in sustainable value creation and decision-making.

- 2. Measurement indicators (social, economic, environmental, and corporate management) can be used at the micro and macro level of enterprise. Less waste is an economic benefit because waste management is related to all business management functions - marketing, production, sales, services, etc.
- 3. The key metrics for measuring the performance of sustainable entrepreneurship are brand awareness and consumer behaviour, responsibility for society and employees, environmentally friendly materials, ease of use and reuse (disposal), zero waste, economic performance.
- 4. Based on the expert evaluations, the expertise level in sustainable entrepreneurship among large Latvian companies is fair with a potential to integrate the sustainable entrepreneurship model into current business practices.

- 5. The general knowledge among large companies is limited to business processes that are associated with the mediation of social issues and the understanding of impact that the corporate management can have on the sustainability performance of the company.
- 6. The self-evaluation matrix in sustainable entrepreneurship serves as a comprehensive tool in the assessment of sustainability-oriented business performance and specific key aspects that may or may not be lacking.

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# THEORETICAL FRAMEWORKS SHAPING INNOVATIVE PRODUCT DEVELOPMENT FOR THE REGIONAL IMPROVEMENT: A MULTIDISCIPLINARY PERSPECTIVE

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#### Abstract

In the realm of innovative product development, a multidisciplinary and scientifically grounded approach plays a pivotal role in shaping the creation of novel solutions. As society faces complex problems and rapidly evolving needs, understanding the scientific methodologies and theories underpinning innovative product development is crucial. Research aim is to comprehensively analyze and synthesize the diverse theoretical foundations from various scientific disciplines that influence the process of innovative product development. Research methods include literature review, content analysis, and expert interviews were employed to identify and categorize relevant theoretical frameworks from various disciplines. The study's key findings emphasize the importance of a multidisciplinary approach in innovative product development. The study highlights the roles of creativity, economics, and psychology in product development, stressing the need to weave diverse scientific theories into a systematic approach for user-centric solutions. The study highlights the integrative nature of innovation by elucidating the diverse theoretical foundations underpinning product development, enhancing understanding of how various scientific theories converge to drive innovation systematically. The findings underscore the importance of a multidisciplinary approach in guiding real-world product development, offering practical insights for innovators, educators, and professionals seeking to optimize the innovation process and create user-centric solutions.

Key words: Innovative Product Development: Multidisciplinary Approaches.

# Introduction

In today's dynamic environment, characterized by rapid technological and business advancements, the ability to innovate remains a cornerstone for organizational sustainability and success. Companies are compelled to navigate a hyper-competitive shaped landscape, dramatically by digital marketplaces and expansive social media channels. The challenge lies in discerning the most effective product development methods from a plethora of available strategies, which hinges on a deep understanding of the theoretical interplay that supports innovation. This paper sets out to provide a critical evaluation of the principal theories and methodologies that underpin the sphere of innovative product development, offering insights that are essential for fostering competitive and groundbreaking products.

There is a limited amount of research on multidisciplinary approaches to innovative product development. Kozlowski & Yamin have analyzed organizational culture and motivation in a multidisciplinary context as key drivers of innovation in organizations (Kozlowski & Yamin, 2010). Comparatively more research has focused on the impact of new technologies on innovative product development in a multidisciplinary context and the interaction of innovation ecosystems in а multidisciplinary approach (Casper & van Waarden, 2021). The multidisciplinary approach to innovative product development is relevant in innovation education, and there is a relatively large body of research on the development process in a multidisciplinary approach, which mainly includes several approaches from innovation and creativity theories (Prestes Joly et al., 2019). The authors of the paper determine the need to identify and conceptualize key underlying theories that contribute to innovative product development in a multidisciplinary context in order to improve organizations' understanding of innovation development in a multidisciplinary context. The aim of this review is to identify key multidisciplinary theoretical frameworks relevant to the overall ecosystem of innovative product development, maximizing the interdisciplinarity knowledge field on innovation development.

#### **Materials and Methods**

This study combines a literature review with interviews to examine the theoretical frameworks behind innovative product development. The literature review analyzes scientific articles, books, and conference papers, while the interviews involve six experts with extensive experience in successful product development. The interviews allow for a detailed exploration of each expert's perspective on the theoretical frameworks. The qualitative nature of the interviews aims to gather nuanced information not found in existing literature. By integrating the results of the literature review and interviews, the study aims to provide a comprehensive understanding of the theoretical foundations of innovative product development. The use of multiple data sources improves the validity and reliability of the study's findings.

#### **Results and Discussion**

The scientific literature is rich in theoretical approaches and methods for innovative product development, incorporating knowledge from different fields - engineering, economics, business management, design, psychology, material science, engineering, etc., while at the same time the scientific literature is highly fragmented across the different theories.
Innovation theory is a frequently discussed method for fostering innovation in scientific literature (Chaminade & Edquist, 2006). Innovation theory is the cornerstone of any study on the development of innovative products, aiming to understand and explain the processes, mechanisms and factors that contribute to innovation in organizations, industries and society at large. It includes a range of theoretical frameworks and models that help researchers, policy makers and practitioners to analyze, predict and promote innovation (Lundvall, 2007). Innovation theories usually start with a definition of innovation, as innovation can cover a wide range of activities, from the development of new products and services to the introduction of new processes, business models and organizational structures. These theories explore the different factors that stimulate and influence innovation. Common drivers include technological development, market demand, competition, government policy and cultural or social factors (Sundbo, 1998). Many innovation theories describe stages or phases of the innovation process, which may include idea generation, research and development, testing, commercialization and diffusion or adoption (Christensen, Anthony, & Roth, 2004). Some theories focus on how innovations diffuse through society, and how they are adopted by organizations. For example, Everett Rogers' Diffusion of Innovations theory (Rogers, 2003) divides adopters into different groups and examines the factors that influence their acceptance of new ideas or technologies, although it also faces significant criticism (Lundblad, 2003). Modern innovation theory often focuses on the complex networks and ecosystems that support and foster innovation (Afonso, Monteiro, & Thompson, 2010). They involve cooperation between businesses, universities, research institutions, government agencies and other stakeholders (Rampersad, Quester, & Troshani, 2010). An important aspect is the concept of open innovation, promoted by Henry Chesbrough. It suggests that organizations can benefit from both sourcing ideas and innovations from external partners and licensing their innovations to others (Chesbrough, 2003). Innovation theories also focus on how to measure and evaluate innovation in organizations. Metrics may include patent applications, R&D expenditure, revenues from new products, but they differ from the economic evaluation of innovation (Brattström et al., 2018). Another important aspect of innovation theory research is to understand the barriers to the introduction or adoption of innovation. These barriers can include risk aversion, resource constraints, regulatory barriers and resistance to change indicators (Sipahutar et al., 2020). Lewis R.'s theory of the '9X Effect' (Lewis, 2023) of balancing innovative product and behavioural change explores why consumers resist adopting innovative products, even when they offer advantages over existing options. Innovation theory itself is multidisciplinary and draws on fields such as

economics, management, sociology, psychology and engineering (Sipahutar *et al.*, 2020). Although it is continuously improved, it does not cover important stages of innovative product development such as costbenefit approaches, regulatory, consumer behavior aspects, etc., which are discussed later in the paper.

Theories of creativity and problem solving provide a framework for organizations to generate creative ideas, identify problems and find effective solutions (Kozbelt, Beghetto, & Runco, 2010). In the context of innovation, these theories help guide the processes of ideation and problem-solving that lead to new products, services and processes. The most important aspects of creativity and problem-solving theories relevant to innovation are divergent thinking, which is a core concept of creativity theories (Baer, 2014). It refers to the ability to generate different solutions in response to problem. Theories of creativity emphasize the importance of encouraging divergent thinking as a prerequisite for finding innovative solutions (Acar & Runco, 2019). Two widely used and described theories of creativity are Design Thinking and User-Centered Design, which are two complementary theoretical approaches to innovation. They focus on creating products and services that meet users' needs and expectations. These methodologies prioritize empathy, iteration, and collaboration to ensure that innovation is user-centered and effective (Oxman, 2017). Usercentered design is a specific approach that puts the user at the center of the design and development process. It focuses on creating products and systems that are intuitive, efficient, and enjoyable for users (Pratt & Nunes, 2012). The traditional problem-solving model (CPS) is a structured approach to fostering creativity. It includes steps such as problem-finding, fact-finding, idea-finding, solution-finding and acceptance-finding. CPS encourages the exploration of multiple perspectives and the use of techniques such as brainstorming and mind mapping (Treffinger, 1995). Flow theory suggests that people are most creative and productive when they are in a state of 'flow', characterized by deep concentration, high motivation and a sense of timelessness (Botticchio & Vialle, 2009). Within theories of creativity, a separate distinction should be made between theories of problem solving, which emphasize the importance of accurately identifying and defining the problem (Weisberg, 2019). This stage involves understanding the root causes of the problem, collecting relevant data and formulating an effective problem statement. Another approach is analytical problem solving, which involves breaking down complex problems into smaller, more manageable parts. Techniques such as root cause analysis, decision trees and SWOT analysis help to identify possible solutions and their impacts (Greiff, Holt, & Funke, 2013). TRIZ (Cerit, Küçükyazıcı, & Şener, 2014) (Theory of Inventive Problem Solving) is a problem-solving theory that provides a structured approach to finding inventive solutions to technical problems. It involves the analysis and application of exemplary inventive solutions in different fields. InnoMatrix is also a problem-solving theory that provides a structured approach to innovation development based on consumers' past behavior in purchasing new products (Batraga *et al.*, 2019).

In the context of innovation development, these theories often intersect, as creativity plays an important role in generating new ideas, while problemsolving strategies guide the process of transforming these ideas into practical and effective solutions (Proctor, 2010). To effectively innovate, both creativity and structured problem solving are needed to address the creation and implementation aspects (Sousa, Monteiro, & Pellissier, 2009). Game theory should be distinguished, which provides a framework for strategizing interactions between different stakeholders or organizations involved in the innovation process (Baniak & Dubina, 2012). It helps analyze competition and cooperation dynamics, make informed decisions, and maximize results in situations where one party's actions impact others.

An important group of theories are cost-benefit approaches, which are used to assess the costs and benefits associated with innovative product development, helping organizations and decisionmakers to analyze the financial and non-financial aspects of innovation, enabling informed decisions on resource allocation, risk management and strategy development. One of the most frequently used approaches and one of the most widely used in the scientific literature is Cost and benefit analyses (CBA), which is a systematic approach to assessing the economic viability of an innovation project by comparing costs with benefits. CBA helps organizations to assess whether the potential financial benefits of an innovation project outweigh the investment required. It takes into account tangible (revenue growth, cost savings) and indirect (improved brand reputation, employee morale) benefits and compares them with direct and indirect costs. Return on Investment (ROI) is a financial indicator that measures the profitability of an innovation initiative by dividing the net benefits (benefits minus costs) by the initial investment. Total Cost of Ownership (TCO) calculates the total cost of implementing and maintaining an innovation throughout its life cycle, including acquisition, operation and disposal costs. TCO is valuable for assessing the long-term financial impact of innovation decisions. Cost-Effectiveness Analysis (CEA) compares the costs of different innovations with their respective outcomes or benefits, often measured in non-monetary units. CEA is particularly useful in healthcare and public policy. It helps organizations to identify which innovation interventions deliver the greatest results relative to their costs, thus allowing informed resource allocation (Avanceña & Prosser, 2022). Cost-Utility Analysis

(CUA) is an extension of CEA by including utility measures or quality-adjusted life years (QALYs) to assess the impact of innovations on quality of life. CUA is commonly used in healthcare to evaluate innovations such as treatments or interventions. It helps decision-makers to assess how innovations affect both the quantity and quality of life, allowing comparisons between different innovations in healthcare. Benefit-Cost Ratio (BCR) is a financial indicator that calculates the ratio of total benefits to total costs associated with an innovation project (Berawi et al., 2017). BCR helps organizations determine whether an innovation initiative is economically viable. Real Options Theory (ROT) extends traditional financial analysis by considering the value of flexibility and the ability to adapt or abandon innovation projects based on changing circumstances. Real Options Theory helps organizations to assess the strategic value of waiting for, expanding or abandoning an innovation project based on market uncertainty and changing circumstances. Opportunity Cost (OC) analysis calculates the value gained or lost by choosing one innovation project over another, or by allocating resources to a particular project. Understanding opportunity costs is essential when prioritizing innovation projects and resource allocation. It ensures that organizations select projects that maximize value and meet strategic objectives (BarNir, 2014).

Theories from psychology and behavioral economics provide valuable insights into how users make decisions, which can aid in the design and adoption of innovative products. Consumer behavior theories, particularly those related to the consumer decision-making process, are crucial for the development of new ideas. There are numerous theories available, including VALS, Maslow's Pyramid, Theory of Planned Behavior, and Cialdini's Principles of Persuasion, that help understand consumer behavior.

There are two related **theories from material science and engineering**. The study of materials at the atomic and molecular level helps to select suitable materials for product design based on their properties (Himanen *et al.*, 2019). Engineering principles are concepts from different engineering disciplines, such as mechanical, electrical, and chemical engineering, that provide insights into the technical aspects of product development and, most importantly, the possibilities (Landry, Amara, & Lamari, 2002).

From an environmental science perspective, **theories related to sustainability**, such as the 'triple bottom line' (economic, social, environmental), are important in the context of innovation, helping to develop environmentally friendly and socially responsible products (Pan, Sinha, & Chen, 2021).

**Regulatory theories** are concerned with legal frameworks and compliance standards to ensure that innovative products meet legal requirements and

safety standards, e.g. ISO standards for innovation development (Manders, Vries, & Blind, 2016).

From an **information theory** perspective, Shannon's information theory can be used to design information-rich products and user interfaces to ensure effective information transfer (Guizzo, 2003).

**Systems Thinking theory** is an approach to innovation that takes into account the interconnections and interdependencies of complex systems. It promotes a holistic view of problems and opportunities, recognizing that changes in one part of a system can affect other parts (Checkland, 1999).

Among **project management theories**, some have revolutionized product development practice. For example, Agile, with its iterative and incremental approach, enables rapid response to changing market conditions (Nerur & Balijepally, 2007). Lean principles, derived from manufacturing, emphasize the pursuit of maximum efficiency. Together, these systems promote flexibility and customer orientation in product development. This theory, based on Eric Ries, emphasizes a scientific approach to the creation and management of successful start-ups and innovative products, iterating rapidly through feedback cycles of 'build-measure-improve' (Ries, 2011).

**Theories such as the Technology Acceptance** Model (TAM) and the Unified Theory of Acceptance and Use of Technology provide insights into users' perceptions of the acceptance of innovative products. These

models take into account factors such as perceived ease of use, perceived usefulness and social impact (Lala, 2014). The concept of a technology readiness scale, which measures the level of readiness of a given innovation in a uniform way, is widely used (Parasuraman, 2000).

The advent of the digital age has fostered the emergence of open source and crowdsourced innovation. These models use the collective intelligence of online communities to design and develop products. Notable examples are Wikipedia, Linux and open source software projects. This approach contradicts traditional notions of product development by emphasizing collaboration and shared ownership (Majchrzak & Malhotra, 2013).

These theories and concepts provide a framework for organizations to understand and overcome the complex process of creating innovative products by integrating scientific understanding with practical application in the organization. Depending on the product and the sector, different theories may play a greater or lesser role in guiding the innovation process. Authors have identified 12 basic groups of theories relevant to innovative product development innovation, creativity, cost & benefit, user behavior, material science and engineering, regulatory, sustainability, information, project management, technology readiness and adaptation, connected systems and risk management theories.



Figure 1. 12 groups of theories relevant to innovative product development.

The theoretical frameworks that shape innovative product development from a multidisciplinary perspective provide a comprehensive view of the multidisciplinary nature of innovative product development. The results highlight the complex interplay of different theories and methodologies in several fields. One of the findings is that successful innovative product development requires a holistic and interdisciplinary approach, taking into account a spectrum of theories from different fields. However, this advantage is only available to organizations that navigate the complex landscape of innovation development.

The discussion centers on the organization's capacity to comprehend diverse innovation theories and explores avenues for conceptualizing methodological approaches to streamline innovation development. The primary goal is to render the creation of high-value innovations more accessible and comprehensible for organizations. The discourse probes the organization's ability to fully grasp the spectrum of innovation theories. It raises questions about the practical feasibility of assimilating and applying these theories within organizational contexts. Consideration is given to how methodological approaches can be formulated to facilitate a clearer understanding of innovation processes within the organizational framework. The discussion contemplates strategies for enhancing the accessibility of innovation theories within organizations. This involves assessing how theories can be communicated and disseminated in a manner that is readily comprehensible to diverse stakeholders. The focus is on making the intricacies of innovation development more understandable. This includes exploring ways to demystify complex theoretical frameworks, ensuring that they resonate with the dayto-day operations of organizations.

Future Research Avenues applies to Practical Application of Theories in terms of multidisciplinary perspective. A call is made for future studies to scrutinize the practical application of innovation theories. This involves analyzing which theories yield more productive outcomes for companies in realworld scenarios. The discussion proposes evaluating the effectiveness of different innovation approaches to identify those that consistently deliver expected results for organizations. The authors advocate for a dynamic outlook on existing theoretical frameworks. They propose that the classification of these frameworks should be subject to constant review and improvement. The ultimate objective is to strive for a more constructive innovation development system. This system should not only be effective but also userfriendly, ensuring ease of use and comprehension for organizations in their daily operations. In essence, the discussion encourages a forward-looking approach, urging organizations to actively engage with and adapt innovation theories. There is a potential for the development of a more practical, constructive, and user-friendly innovation framework that aligns seamlessly with the operational needs of organizations. This iterative process of review and improvement is envisioned as a pathway to foster a culture of innovation that is both impactful and accessible in organizational settings.

#### Conclusions

- 1. The field of innovative product development is constantly evolving, and new theories, methodologies and tools are constantly being introduced from both academia and industry.
- 2. As important as developing new theories and approaches is fostering a multidisciplinary understanding of the complex nature of innovation in organizations, and encouraging organizations to understand more appropriate choices in innovation development.
- 3. The literature review highlights the dynamic and multifaceted nature of innovative product development, emphasizing the importance of embracing a diverse set of theoretical frameworks for informed decision-making and successful outcomes.

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# INTELLECTUAL PROPERTY RIGHTS IN LATVIA: ISSUES OF VALUATION AND ACCOUNTING

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#### Abstract

Nowadays, when the economic development of countries is more and more influenced by knowledge-based, innovative entrepreneurship, particular attention is paid to the application and protection of intellectual property. Enterprises can acquire intellectual property rights in various ways externally and such rights can also be generated by enterprises internally: they launch and subsequently produce new or improved products and services (research and development) and ensure the protection of intellectually intensive products (patents, trademarks, computer software, etc.). Thus, it is important to study the valuation and accounting of intellectual property rights. The aim of the research is, on the basis of the studies of intellectual property rights accounting policy in Latvia, to identify the shortcomings related to the valuation and accounting of intellectual property rights data, to valuate accounting policy for IPRs; to identify shortcomings related to the valuation of identified shortcomings. The results of research enable to draw a conclusion that the requirements of the laws and regulations of Latvia do not prevent from the capitalization of intellectual property rights as intangible assets; however, it is necessary to revise and improve some requirements. In the conclusion of research, the authors have elaborated recommendations for the elimination of identified shortcomings.

Key words: intellectual property rights, intangible assets, valuation, accounting.

#### Introduction

The scientists have been studying and discussing the most appropriate valuation and accounting approach to intangible assets (hereinafter - IA), including intellectual property rights (hereinafter - IPRs) for a long time.

Several scientists, for example, Flignor & Orozeo (2006), Bochańczyk-Kupka (2017) have provided their conclusions on the measurement of value methodology for IA and/or intellectual property (hereinafter – IP). Bochańczyk-Kupka (2017) provides information on the quantitative and qualitative approaches to be applied for the valuation of IP and admits that the qualitative approach gives more generic overview of the IP and this method is always less precise than quantitative one. Flignor & Orozeo (2006) offer IA and IP valuation pyramid that comprises the quantitative valuation methods, and they admit that all methods are in principle applicable equally.

Several scientists also present conclusions on the recognition of IA in the financial reports. According to authors, at present, one of the most topical studies have been performed by Penman (2023) who analyzed specialists' views and discussed on the most appropriate accounting for IA, including internally generated IA. This scientist concludes that investments (tangible and intangible – auth.) are booked to the balance sheet under current accounting standards only if future benefits are probable with relatively low outcome uncertainty.

Besides, several scientists study IA and/or IPRs accounting policy of their countries. Thus, Umantsiv *et al.* (2023) analyze the international experience and Ukrainian practice of valuation of intangible assets and intellectual property rights in the process of their commercialization, as well as in the accounting and reporting system in the context of economic instability. Sarkar & Mitra (2023) have studied a method to identify and value IP in its own right, in the

light of applicable Indian accounting standards and that of some leading economies of the world.

The research aim is, on the basis of the studies of intellectual property rights accounting policy in Latvia, to identify the shortcomings related to the valuation and accounting of intellectual property rights and to develop recommendations for their elimination. The following research tasks are subject to the aim:

1) to study IPRs concept, regulatory framework and statistical data;

2) to valuate accounting policy for IPRs;

3) to identify shortcomings related to the valuation and accounting of IPRs;

4) to develop recommendations for the elimination of identified shortcomings.

The research basically covers the period from 2000 to 2024.

The limitation to the research – the research authors do not include IA valuation according to IFRS 3 'Business Combinations' because this issue has been in detail covered in specialized literature and scientists' publications, as well as it is a broad issue, and, as a result, the determined volume of the paper would be exceeded.

#### **Materials and Methods**

Research methods: the monographic and descriptive methods, analysis and synthesis, the graphic method. The present research is based on various scientific publications, publicly available documents, information available in databases and other sources.

#### **Results and Discussion**

#### IPR concept, regulatory framework and statistics

The concept found in the international law – intellectual property – is well known in any country, because as early as the 19<sup>th</sup> century all international relations regarding the protection of IPRs were

conducted within either of two major groupings:

- the 1883 Paris Union for the Protection of Industrial Property;
- the 1886 Berne Union for the Protection of Literary and Artistic Works.

This concept gained a stable legal standing in the 20th century, when in 1967 a diplomatic conference was held in Stockholm at which the Convention Establishing the World Intellectual Property Organization (hereinafter – WIPO) was adopted.

Before the Second World War Latvia was a member of both the Paris Union and the Berne Union, and the membership was renewed on September 7, 1993 and August 11, 1995, respectively. On January 21, 1993 Latvia became a member of the WIPO.

When comparing IP explanations included in WIPO (*What is intellectual*..., 2020) and EU documents (EU, Summaries, *Intellectual Property*, 2024) it was

established that they are basically identical. Namely, IP is grouped in two main categories: industrial property (main types: patents for inventions, industrial designs, trademarks and geographical indications) and copyright and related rights (main types: literary, artistic and scientific works, including performances and broadcasts). Intellectual property objects, created as a result of a human intellectual work, are protected by IPRs which, as indicated in the EU documents, allow owners - creators as inventors or artists, or any rights holders - to decide how, when and where their creations are used and/or exploited (EU, Summaries, *Intellectual Property*, 2024).

IP regulatory framework is complicated because almost every type of IPRs is regulated by a separate law, and a different protection period has been determined for each type of IPRs. The present situation in Latvia is presented in Table 1.

Table1

Regulators	v framowark and	agal protection	norial for intall	actual nronarty r	ights in Latvia
Regulatory		egai protection	periou for milen	ectual property r	ignus in Latvia

Trut all a struct		
Intellectual	Regulatory framework	Legal protection period for intellectual property
property rights		rights
Patents	Patent I aw 2007 (Chapter IV)	limited protection period - 20 years since the date of
	Tucht Edw, 2007. (Chapter TV)	patent application if it is renewed on a annual basis
	Copyright Law, 2000. (Chapter VI)	limited protection period – the lifetime of the author/co-authors + 70 years following the death of the author/the last co-author
	works, musical works, audio-visual works, etc. (Chapter II)	any person, who after expiration of a copyright lawfully publishes/communicates to the public a
	protected derivative works: translations, revised works, annotations, musical arrangements, encyclopedias, etc. (Chapter II)	previously unpublished work, shall acquire rights which are equivalent to the economic rights of an author and shall be in effect for 25 years from the first
Convright	······································	publication/communicating to the public of the work
Copyright		limited protection period - 15 years since January 1 of the year following the day of database development
	databases (Chapter IX)	if a database has been made available to the public before the expiration of the initial protection period of 15 years, the period of protection shall begin on January 1 of the year following the day when the database was first made available to the public and shall be in effect for 15 years
Trademarks	Trade Mark Law, 2020. (Chapter III.	
	Chapter V) internationally registered trademark (Chapter X) indications of geographical origin (Chapter XII)	indefinite protection period, if the registration of a trademark is renewed once in 10 years
Designs	Law on Designs, 2004. (Chapter III, Chapter IV, Chapter VIII)	limited protection period – 25 years if renewed after every 5 years
Integrated circuits	Law on the Protection of Topographies of Semiconductor Products, 1998. (Chapter III)	limited protection period – 10 years since January 1 of the year that follows the year, when an application was submitted or the commercial use of topography has been commenced
Plant variety and breeder`s rights	Plant Varieties Protection Law, 2002. (Chapter I, Chapter III)	limited protection period – 25 years, but for potatoes, vines, and tree species – 30 years if renewed on an annual basis
Know-how	Cabinet Regulation No. 798, 2008	indefinite period if preserved as a secret

Source: authors' construction based on provisions included into indicated laws and regulations.

Table 1 shows that the legal protection period for IP is mostly limited by a particular period of time, for example, for the patents these are 20 years (providing that the owner of a patent renews his or her rights on an annual basis). IPRs with indefinite period of protection include trademarks and indications of geographical

origin. There is no definite period determined for the protection of trademarks because it is impossible to foresee for how long the management of an enterprise would consider the necessity to maintain and renew these trademarks for the coming 10 years. Usually, an enterprise registers a trademark and later renews its protection in order to distinguish its own goods/services from the goods/services of other enterprises and to protect it against unlawful use, as well as to ensure the identification of the enterprise and to preserve the customers' trust. Particular situation is related to the indications of geographic origin protecting enterprise's foodstuffs, spirits, agricultural produce of particular geographic origin, reputation and/or qualities. They are protected for an indefinite period without registration at the Patent Office (Trade Mark Law, 2020).

Table 1 also shows specific IPRs - know-how or special knowledge, which is an entity of non-patented practical information that occurs as the result of experience and practice and is confidential (not publicly known and easy available), essential (includes information important in the production of goods or in the application of technological process), and it is possible to examine (such knowledge is described sufficiently in order to make it possible to examine whether it is confidential and essential) (Regulations Regarding Non-subjection..., 2008). Know-how identification and analysis takes place within the framework of enterprise research and development (hereinafter - R&D) works. Thus, enterprises identify the knowledge they have accumulated regarding the production and sales of their goods and decide which parts of this knowledge can be revealed by applying for a patent and which should be kept in secret, thus moving them to the know-how category.

On the homepage of the Patent Office of the Republic of Latvia, there is statistics published on the number of patents, designs and trademarks registered in Latvia from 1992 to 2023. 'Figure 1' shows information on the last six years (from 2018 to 2023).



Figure 1. Number of IPRs registered in Latvia, 2018-2023.

Source: authors' construction based on the data of the Patent Office (2024) of the Republic of Latvia.

In 'Figure 1', we can see that from 2018 to 2020 the total number of registered intellectual rights was stable: there were 4547 registrations on average per year during this

period. But during the last three years we can observe the decrease of the total number of registered rights by 26%: starting from 4251 registrations in 2021 down to 3151 registrations in 2023. It is obvious that such a decrease of the number of registered rights is related to COVID-19 pandemic, when economic activities and business processes were limited.

When analyzing the structure of registered IPRs, we can see that during this period, out of all intellectual property rights registered at the Patent Office of the Republic of Latvia, on average most of all there were trademarks (57% of all registered rights) and patents (40% of all registered rights) registered, and the lowest average number of registered rights (3% of registered rights) concerns designs. Such structure of intellectual property rights, when trademarks prevail, is characteristic on the whole globally. According to WIPO IP Statistics Data center data, of all globally received IP registration applications, the proportion of trademark applications in 2020 constituted 57%, in 2021 – 70%, and in 2022 – 66% (WIPO statistics database, 2023).

## IPR accounting policy

IPRs owned by enterprises may be recognized as IA. When making a decision about the inclusion of IP among IA, there shall be taken into account the same provisions, which are related to the recognition and accounting of any other IA.

For the accounting of IA at the Latvian enterprises, those laws and regulations of the Republic of Latvia are binding (the most important ones: LR Law 'On Statements and Consolidated Annual Annual Statements', Cabinet regulation No. 775 'Regulation for the Application of the Law on Annual Statements and Consolidated Annual Statements', etc.), which are based on the EU Directives in the field of accounting. But those Latvian enterprises that must or choose to organize their accounting according to IAS/IFRS, for the accounting of IA shall use IAS 38 'Intangible assets', which has been adopted in the EU by European Commission Regulation No. 2023/1803 adopting certain international accounting standards in accordance with 'Regulation (EC) No 1606/2002 of the European Parliament and of the Council' (hereinafter – EU Regulation No. 2023/1803).

In order to recognize IPRs as IA, they shall comply with the definition and recognition criteria of IA. The authors studied these conditions and compared the laws and regulations of Latvia, IAS 38 and European Parliament and of the Council Directive 2013/34/EU 'On the annual financial statements, consolidated financial statements and related reports of certain types of undertakings' (hereinafter – EU Directive No. 2013/34). The authors have found that there are no definition and recognition criteria determined for IA in the EU Directive No. 2013/34. It could be explained by the terms of the EU Directives. Namely, the EU Directives include the goals set for the EU Member States, and every EU Member State adopts its own laws and regulations to achieve these goals. When comparing the definition and recognition criteria determined in the regulatory enactments of Latvia and those provided in the international standard, we can state that there are no significant differences.

In most cases, IPRs owned by an enterprise, comply with IA definition (they have no physical substance, they are no monetary assets) and recognition criteria (identifiability, control, existence of future economic benefits). It could be based on the fact that, first, these are rights granted to the enterprise with a definite of indefinite legal protection period (see Table 1) or the enterprise acquires these rights on the basis of different contracts, for example, trademark licence contract. Second, IPRs

possessed by enterprise, ensure economic benefit flow in the future due to their use at the enterprise and/or due to permission to use them by other enterprises, for example, a patented invention is allowed to be used by others on the basis of a licence contract.

The authors admit that, of course, not all IPRs possessed by enterprise comply with IA recognition criteria. Sarkar & Mitra (2023) also emphasize that IPRs may be shown as intangible assets but all intangible assets are not IP assets.

One of the criteria for the recognition of IPRs as IA is the ability to carry out the credible valuation of their value. Valuation provisions depend on the type of origin of these rights at the enterprise (see Table 2).

Table 2

Comparison of the initial valuation provisions for the intellectual property rights recognized as intangible
assets in the laws and regulations of Latvia and IAS 38, IAS 23, IAS 20

Types of the origin of	EU Regulation No.2023/1803	Laws and regulations of Latvia	
intellectual property rights	/IAS 38, IAS 23, IAS 20/		
Acquired separately (externally)	<ol> <li>value consists of:</li> <li>purchase price + non-refundable purchase taxes - trade discounts</li> <li>any directly attributable cost of preparing the asset for its intended use (IAS 38, 27)</li> <li>shall capitalize borrowing cost that are directly attributable to the acquisition of a qualifying intangible asset as part of the cost of that asset (IAS 23, 8)</li> <li>if payment for an intangible asset is deferred, its cost is the cash price equivalent (IAS 38, 32)</li> </ol>	purchase costs – the same as in IAS 38, 27 ( <i>Law on Annual</i> <i>Statements</i> , Section 14) the loan interest received for the establishment of intangible assets may be included in production cost price of the relevant newly established objects ( <i>Law on Annual</i> <i>Statements</i> , Section 28)	
Acquired as part of a business combination	fair value, which reflected market participants expectations (IAS 38, 33)	no provisions	
Acquired by way of a governmental grant	<ol> <li>nonmonetary asset and grant are evaluated at fair value or nominal value (IAS 38, 44)</li> <li>nonmonetary asset carrying value = nonmonetary asset value - grant value (IAS 20, 24)</li> </ol>	the same as in IAS 38, 44 ( <i>Regulation for the Application</i> No. 775, Sections 6 and 7)	
Acquired by exchanges of assets	<ol> <li>fair value of the received asset if its not possible to determine</li> <li>fair value of the given away asset if its not possible to determinec</li> <li>carrying amount of the given away asset (IAS 38, 45)</li> </ol>	no requirements have been determined for intangible assets, but the requirements for fixed assets comply with the provisions of IAS 38 ( <i>Regulation for the</i> <i>Application</i> No. 775, Section 79)	
Internally generated	research phase – recognized as an expense (IAS 38,54) development phase – capitalized if the appropriate conditions are met (IAS 38, 57) directly attributable costs necessary to create, produce and prepare the asset (IAS 38, 66) shall capitalize borrowing costs that are directly attributable to the construction or production of a qualifying intangible asset as part of the cost of that	the same as in IAS 38, 54., 57., 66. ( <i>Law on Annual Statements</i> , Section 29 and <i>Regulation for the</i> <i>Application</i> No.775, Section 202) the loan interest received for the establishment of intangible assets may be included in production cost price of the relevant newly established objects ( <i>Law on Annual</i>	

Source: authors' construction based on provisions included into indicated laws and regulations.

In Table 2, we can see that there are different provisions determined for the initial valuation of IPRs for the Latvian enterprises depending on what regulatory documents they organize their accounting. As a result of comparative research, the authors identified three differences and two types of potential IP origin, which have no valuation provisions in the laws and regulations of Latvia. The first difference concerns the provisions of borrowing cost capitalization: in conformity with the requirements set in the regulatory enactments of Latvia, the inclusion of such costs into the initial value of both externally acquired and internally generated is permitted, but it is not compulsory, as it is in compliance with the international standard. The second difference is related to the determination of the initial value of IPRs, payment for them is deferred. In this case, in conformity with the international standard, there shall be valuated the present value of IPRs obtained by discounting sums to be paid in future. In the regulatory enactments of Latvia, such valuation nuance is not envisaged. The third difference is the fact that Latvian regulatory enactments do not provide the second method how to determine the initial value of IPRs fully or partially financed by a government grant. Namely, there is no method provided when the value of financed IPRs is decreased by received government grant. It should be pointed out that in IAS 20 'Accounting for Government Grants and Disclosure of Government Assistance' both methods of presentation in financial statements of grants (or the appropriate portions of grants) related to assets are regarded as acceptable alternatives (EU Regulation No. 2023/1803, IAS 20, 25). However, as the advantages of the second method there should be mentioned the fact that when the grant is subtracted from the value of the asset to be financed, we obtain that the asset (including IPRs) is disclosed in the financial report according its substantiated lowest value or it may be called also its true economic value, which enables the main users of financial reports (investors, creditors) to see the true acquisition costs of the asset. While continuing the comparative analysis (see Table 2), we should critically assess that there are no provisions in the regulatory enactments of Latvia how to valuate IPRs, as they have been acquired as a part of a business combination. The only thing determined in this relation is that expenses related to the acquisition of an undertaking may be indicated in the item 'Goodwill' if they cannot be referred to other items of the balance sheet asset (Law on Annual Statements..., Section 29), which does not provide an answer to the question – how in this case the value of the taken possession of assets shall be determined. There are also no provisions in the regulatory enactments of Latvia how to valuate IPRs if they have been acquired by exchange of assets. At the same time, it should be pointed out that in the regulatory enactments of Latvia there are provisions included for the valuation of fixed assets acquired as result of the exchange of assets; there provisions are identical to those included in IAS 38 regarding valuation of IA. The differences of the provisions for the valuation of IPRs initial value and the lack of provisions limit the comparability of the financial indicators of Latvian enterprises.

Thus, the enterprises can themselves generate IPRs internally and acquire them externally in different ways (see Table 2).

In accounting, expenditure of resources related to the development of internally generated IPRs is recognized as the costs of R&D works, and, when the respective conditions are met, the value of resources used for developmental works is capitalized in the balance sheet item 'Development costs'. Then the management of the company makes an important decision – whether different innovations (new or

improved products, technological processes and other innovative solutions) created as a result of R&D works will be registered and/or protected by IPRs (patents, design, integrated circuits), or the innovations would be preserved as a secret (know-how). If the management of the company decides in favour of the protection of innovation, for example, registers a patent, then the costs of patent development and the costs for the registration at the Patent Office of the Republic of Latvia are capitalized in the balance sheet item 'Concessions, patents, trademarks and similar rights' and determine its amortization period. Whereas, if the innovation is transferred to know-how patent category. then the amortization of developmental costs is started.

In accounting, in different ways externally acquired IPRs are disclosed in the balance sheet item 'Concessions, patents, trademarks and similar rights'. When IPRs are initially recognized and valuated as IA, their further accounting policy is important. In Latvia, for the further registration of IA there is one accounting method - cost method, but, in conformity with the provision of Directive No. 2013/34, it is not allowed to use the revaluation method. The cost method provides that after initial recognition, intangible assets, including IPRs, shall be carried at their cost less any accumulated amortisation and any accumulated impairment losses. In order to carry out further bookkeeping of IPRs, there shall be determined their useful life, which may be finite or indefinite period because it is necessary to connect useful life to the legal protection period of IPRs (see Table 1). The regulatory enactments of Latvia do not provide for a finite period of IPRs useful life and a particular method for the calculation of amortization. Irrespective of the fact, whether an enterprise has determined finite or indefinite useful life for IPRs, they are subject to the test of value reduction if indications of internal or external origin are identified, which might indicative of the decrease of value.

# Shortcomings identified in relation to IPRs valuation and accounting

As a result of the studies of various sources and literature, several shortcomings in relation to the valuation of IPRs and accounting were identified in Latvia.

First, information provided on R&D costs is not always included in the annual statements of Latvian enterprises. In the regulatory enactments of Latvia, since 2016 it has been provided that medium and large enterprises, in the annexes of their financial statements, shall present also detailed information on R&D costs (*Law on Annual Statements...*, Section 53(1)17)), but for other enterprises the disclosure of such information is voluntary. Besides, the data on the activities carried out by enterprise in the sphere of R&D shall be disclosed also in the management report. However, not always the information on R&D costs is provided in the annual statements of Latvian enterprises. Thus, Kiopa, the Member of the Board of Lursoft LTD, points out that in the statements for the 2022 this item was separately disclosed by 439 enterprises, which is less than 0.5% cases (Kirsons, 2024a). It should be noted that, according to the entrepreneurs' views, many enterprises in Latvia actively develop new products or improve present operational processes, namely, they carry out R&D works, but not always the costs of such works are registered separately in accounting. During the interview at the periodical 'Dienas bizness', Binde, Chairperson of the Board of LMT LTD, mentions that smaller enterprises might act like that, and they really do (include R&D costs into the costs of enterprise's basic activities: production costs, personnel costs, etc. - auth.), but this is not the case of large enterprises that also invest in R&D most (Kirsons, 2024b). Information on R&D expenditures in the Baltic States, the authors present in Figure 2.





Source: authors' construction based on official statistics portal data in Latvia, Estonia and Lithuania.

As we can see in 'Figure 2', Lithuania is the leader according to R&D expenditures, but Latvia, unfortunately, is the last among the Baltic States. It should be pointed out that R&D expenditures is also one of the main indicators characterizing the innovative capacity of countries because the successful result of R&D are innovations, which we could choose to protect by means of IPRs. The fact that not all Latvian enterprises provide in their annual statements the information on R&D activities, directly influences the global rankings of Latvia according to the Global innovation index, where in 2023 Latvia was in the  $37^{th}$  place, Estonia – in the  $16^{th}$  place, Lithuania - in the 34<sup>th</sup> place among 132 countries of the world (Global innovation index..., 2023). As one of the main reasons why Latvian enterprises in their annual statements do not disclose R&D expenditures separately, Kiopa, Member of the Board of Lursoft LTD, points out the complex registration of these expenses in the accounting. Namely, in order to disclose R&D expenditures separately, it is necessary to separate and register clearly the involvement of employees in the development of a service, improvement of goods, as well as there should be separated the use of other resources for these activities.

Therefore, the enterprises include R&D expenditures into other items – production costs, personnel costs, etc. (Kirsons, 2024a). The authors only partially agree with the above mentioned point of view because the organization of accounting, including classification of enterprise expenditure, considerably depends on the enterprise management views in this aspect. Besides, as it was mentioned above, it is provided in the laws and regulations of Latvia that separate disclosure of R&D expenditures in the annual statements is compulsory for large and medium enterprises, but for other – voluntary.

Second, the regulatory enactments of Latvia provide for a considerable limitation of the capitalization of enterprise development costs. Namely, the development costs may be included in the balance sheet (capitalised) provided that while the initial value of the object of development costs is not completely written-off, profit distribution shall not take place unless reserves available for distribution and undistributed profit amount of previous years is at least equivalent to the amount of the initial value of development costs not written off (Law on Annual Statements..., Section 30). This provision has been fully adopted from EU Directive 2013/34 - Chapter 3, Article 12, Paragraph 11, Subparagraph 3, not taking into account that Paragraph 11, Subparagraph 5 of the same Directive provides that in exceptional cases, the Member States may permit derogations from the third subparagraphs. Such derogations and the reasons therefore shall be disclosed in the notes to the financial statements. Unfortunately, people who elaborated the regulatory enactments of Latvia have not taken into account the exception of the Directive. Thus, the present regulation does not facilitate the capitalization of developmental costs because the value of developmental costs recognized in the balance sheet limits the distribution of enterprise profit to the owners, but instead the developmental costs are immediately written off to expenditure. When assessing such accounting policy according to taxes, of course, it should be pointed out that immediate inclusion of developmental costs into the expenditures, immediately decreases the profit to be distributed and, along with it, also the amount of enterprise income tax (hereinafter - EIT). Whereas the capitalization of developmental costs and their gradual inclusion into the expenditures within the period of time, which is not longer than 10 years (Law on Annual Statements..., Section 31 (2)), decreases the profit to be distributed and thus also the amount of EIT gradually, but at the same time limits the sum of the profit to be distributed. It is important to emphasize that, without capitalization of developmental costs, the balance sheet does not provide clear and true view on all real enterprise resources that potentially will create economic profit in the future. The additional argument in favour of the capitalization of developmental costs is the fact that in both regulatory enactments of Latvia (Law on Annual Statements..., Section 1, Regulation for the Application..., No.775, Section 202) and IAS 38 (Sections 18, 57) the provisions for the classification of IA and the provisions for the capitalization of developmental costs are identical according to the content. The fulfilment of these provisions ensures that the capitalized developmental costs will potentially create economic profit for the enterprise in the future, which is one of the bases for the capitalization of any resource in the balance sheet. Therefore, according to authors' point of view, it is necessary in Latvia to re-evaluate at the national level the provisions of EU Directive No. 2013/34 in relation to the limitations for the capitalization of developmental costs and to use the relief arrangements provided by Directive.

It should be also mentioned that in Latvia, as a result of tax reform, since 2018 there are no EIT exemptions related to the costs of R&D works. In the period from 2014 to 2017, it was provided that the sum taxable with EIT should be reduced by R&D expenditures by applying the increasing coefficient 3, if the intellectual property created as a result of R&D work is expropriated within 3 taxation periods (On Enterprice Income Tax, Section 6.6 (1), (4)). The above mentioned EIT calculation policy, when the taxable sum was reduced by triplicated R&D expenditures, additionally stimulated Latvian enterprises to carry out such activities. The authors believe that it would be necessary, at the national level, to consider the possibility of EIT exemption for the enterprises performing R&D works.

Thirdly, there are shortcomings in the provisions regarding the payment for the equity capital of capital companies by property contribution, which may be also IPRs. The Commercial Law allows using IPRs as a property contribution to the equity capital of companies, pursuant to certain limitations and rules of valuation. Property contribution is assessed by an expert who is included into the list approved by the Patent Office of the Republic of Latvia (2024). Exception is the founders or participants of a limited liability company who have the right to perform the assessment themselves if the total value of property contributions do not exceed EUR 5,700, and the total value is less than a half of the amount of equity capital. Besides, the assessment shall be carried out according to the usual value of the relevant property or rights. The IPRs as a property contribution may be used to pay the equity capital if the rights conform to 2 criteria: 1) they can be assessed in terms of money, and 2) they can be used for the capital company's business activities (Commercial Law, Sections 153, 154). The authors believe that these regulations are deficient because they do not include all the criteria for recognising an element of an economic transaction as an asset, even though the contribution, after its inclusion in the equity capital, is treated as an IA. It is essential to note that the IP to be contributed must be exploitable in the commercial activities of a capital company; however, the

sphere of these activities depends on management strategies, and often it can be seen that a newly founded enterprise is expected to be active in one or more spheres, but after changes in market and other conditions the priorities may be altered.

The authors suggest supplementing the rules which regulate contributions to equity capital – and allow investing IPRs if they can be valued in money terms and used in commercial activity of the enterprise – with these criteria: 1) industrial IPRs must be registered at the Patent Office of the Republic of Latvia, and 2) IPRs must bring the enterprise future economic benefits or create conditions for receiving them.

## Conclusions

- 1. There are different types of intellectual property and almost each of them is regulated by its own regulatory framework.
- 2. Not all intellectual property rights possessed by enterprises comply with the criteria for the recognition of intangible assets.
- 3. In Latvia, the initial valuation of the intellectual property rights recognized as IA and further accounting policy depend on the fact in compliance to which regulation the accounting is organized.
- 4. Not always the annual reports of Latvian enterprises provide information on R&D costs directly influencing rankings of Latvia in the world according to the Global innovation index.
- 5. In the regulatory enactments of Latvia provide for considerable limitations regarding the capitalization of enterprise developmental costs, thus the financial statement of an enterprise does not provide clear and true view on all real enterprise resources that potentially will create economic profit in the future.
- 6. There are shortcomings in the business regulatory enactments of Latvia regarding the payment for the equity capital of capital companies by property contribution, which may be also IPRs.
- 7. It is necessary in Latvia to re-evaluate at the national level the provisions of EU Directive No. 2013/34 in relation to the limitations for the capitalization of developmental costs and to use the easement provided by Directive.
- 8. It is necessary in Latvia, at the national level, to consider the possibility of EIT exemption for the enterprises performing R&D works.
- 9. In Latvia, at the national level, it is recommended to make a decision to supplement the provisions regarding the payment for the equity capital of capital companies by property contribution with the following criteria if IPRs are used as a property contribution: first, industrial IPRs must be registered in the Patent Office of the Republic of Latvia, and, second, IPRs must bring the enterprise future economic benefits or create conditions for receiving them.

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# IMPACT EVALUATION OF THE RURAL DEVELOPMENT PROGRAMME SUPPORT TO SMALL FARMS WITH REGRESSION DISCONTINUITY DESIGN

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### Abstract

The viability of small farms and their participation in the market are demanding issues of the European agricultural policy. So it is important to appraise the most effective support measures to address these topics. The research objective is the evaluation of the net direct impact of the Latvian Rural Development programme (RDP) support to small farms on the farm economic indicators such as Balance, Utilized Agricultural Area, Intermediate Consumption, Labor and Productivity. To reach the research objective, Regression Discontinuity Design (RDD) method is applied. An outstanding advantage of the method is that the assessment can be carried out in conditions of limited data availability, when the larger number of farming indicators are unavailable and application of other methods is not appropriate. The results of the research prove that Program support contributes to the increase in all five indicators concerned. According to the specifics of the selected method, a single RDP sub-measure has been chosen for the study aimed directly at small farms. Applying the RDD method, a positive impact of support on indicators such as production subsidy and tax balance, agricultural land and productivity for a single beneficiary has been observed. A less pronounced positive impact on employment has been found. The impact on intermediate consumption expenses is small and positive. At the national level, the support has contributed to the substantial increase in the relevant indicators in the group of small-sized farms.

Key words: Rural Development Programme, Small Farms, Regression Discontinuity Design, Net Impact.

## Introduction

The support and development of small farms recently has gained a momentum as a crucial issue within the Common Agricultural Policy (CAP). According to the European Commission, the problem of unequal income distribution among different size of farms is urgent (European Commission, 2021). So redistribution of support to smaller farms is considered essential. Therefore, the development of small farms is promoted through support programmes. Evaluating the effectiveness of support measures specifically tailored for small farms is challenging, as the availability of necessary data and information often is limited. Thus in the study the RDD method has been preferred for the assessment of the effectiveness of the support of small farms in Latvia Due to it's suitability in cases when data are scarce. The research objective is the evaluation of the net direct impact of the Latvian Rural Development programme support to small farms on the farm economic indicators such as Net Balance of Subsidies and Taxes, Utilized Agricultural Area (UAA), Intermediate Consumption, Labour and Productivity. The productivity is expressed as Net Turnover per Annual Working Unit (AWU). To reach the research objective, RDD method has been applied.

#### **Materials and Methods**

In this study the direct impact of sub-measure 6.3 (support for starting up a business by developing small farms) of Measure 6 'Farm and business development' of the Rural Development Programme 2014-2020 has been estimated. The sub-measure provides start-up aid of EUR 15 000 for farms with the net turnover or standard output (SO) in the year before receiving the support falling within the range from EUR 2 000 to EUR 15 000. As the unpublished data from Farm Accountancy Data Network (FADN) used for the study have the lowest threshold set at the EUR 4 000

EUR, only the upper eligibility limit was relevant. Total number of small farms for the extrapolation of the results at the farm size sub-sector level was obtained from Farm Structure Survey by National Statistics Office (CSP, 2020), where the lower threshold for the SO is set at the EUR 2 000. These lower threshold discrepancies would lead to certain selection bias. Moreover, the selection is based upon the Net Turnover which does not necessarily correspond to the respective SO. Hence, the extrapolated results have to be perceived with caution. The highest intensity of the implementation of the submeasure occurred from 2016 to 2019, so the farms conforming to the upper threshold criteria in 2015 were selected. To avoid the selection bias due to the possible impact of support from other measures only 33 farms that received support exclusively in submeasure 6.3 were included in the treatment group of the data panel. For controls, 113 eligible farms without any programme support were selected along with 79 farms with a Net Turnover falling within the EUR 15 000 - EUR 25 000 range limits.

The RDD first was applied in the evaluation of the USA national college student scholarship programs by Thistlewaite and Campbell (1960) by matching two groups of nearwinners in a competition on several background variables. After that the method was somewhat disregarded until it was enlivened by Goldberger (2008) in the analysis of compensatory school educational programs. The method compared to other quasi-experimental design methods has its advantages as additional pre-treament variables are not needed. Moreover, the values of the dependent variable are measured only once at a single point of time. Nevertheless, similarly to other methods data on untreated units are necessary which almost always prove to be a problem. Traditionally, support programmes require only data on participants. The

method also could yield results with low statistical significance if there is no marked change in the dependent variable at the cutpoint. Usually analysis begins with an examination of the scatterplot of the outcome variable and rating variable. In most cases, the relationship between these variables is non-linear. With respect to populations two types of design can be distinguished (Battistin & Rettore, 2008). In the 'sharp' design all units on both sides of the cutoff either receive or do not receive their treatment, thus the treatment variable is binary. In the Type I 'fuzzy' design, there are units in the treatment group which do not receive treatment referred to as 'no-shows'. In the Type II 'fuzzy' design, there are both 'no-shows' and units in the control group which receive treatment referred to as 'crossovers'. In 'fuzzy' design treatment is assigned based upon the probability of receiving the support. Then the probabilities are calculated as the share of receivers within the treatment or control groups. As a rule, RDD analysis begins with an examination of a scatterplot with an outcome variable plotted on the vertical axis and the independent or rating variable plotted on the horizontal axis. The scatterplot shows whether there is a discontinuity in the outcome variable at the cutoff point. The observed discontinuity justifies further analysis. Bloom (2012) suggests two types of strategies for the correct specification of such functional form. Parametric or global strategy uses all observations in the sample. Nonparametric or local strategy uses only the observations that lies in the vicinity of the cutpoint (called a bandwidth). The rating variable can be centered on the cutpoint by including a new variable  $x_i - c$  in the model. Then the most common approach to estimation using an RDD can be expressed with the equation:

$$y_{i} = \beta_{0} + \sum_{j=1}^{m} \beta_{1j} (x_{i} - c)^{j} + \beta_{2} t_{i} + \sum_{j=1}^{m} \beta_{3m} (x_{i} - c)^{j} t_{i} + \varepsilon_{i}$$
(1)

where  $\beta_0$ ,  $\beta_1$ ,  $\beta_2$ ,  $\beta_3$  – regression coefficients;  $y_1$ , ...,  $y_n$  – vector of the dependent variable:  $x_1$ , ...,  $x_n$  – vector of the independent variable;  $t_1$ ,...,  $t_n$  – vector of the treatment variable;  $\varepsilon_1$ ,...,  $\varepsilon_n$  – vector of residuals; c – cutoff point; n – number of observations; m – polynomial degrees.

The coefficient  $\beta_2$  shows the average treatment effect on the treated (ATT). Usually, only linear and secondorder polynomial models are applied. Gelman and Imbens (2019) think that higher order polynomial regressions are a poor choice in regression discontinuity analysis because imprecise estimates due to noise, sensitivity to the polynomial's degree, and inadequate coverage of confidence intervals. Huntington-Klein (2021) recommends the use of local regression to obtain 'smoothed' values of the dependent variable for the estimation with the linear or polynomial model. Locally weighted polynomial regression method (LOESS) was originally proposed by Cleveland (1979). The set of the independent variable is divided into subsets using a 'smoothing parameter' selected by the user, which shows the size of the subsets. For every value of the independent variable, a respective number of nearest neighbours are included in a subset. For each localized subset, weighted least squares regression (WOLS) introduced by Aitken (1935) is performed to find the coefficients for calculation of adjusted values of the dependent variables by simple regression. First, the distances from each point in a subset to the point of estimation are calculated. Then the distances are scaled by the maximum distance between all possible pairs of points in a subset. For calculation of the weights from scaled distances, most commonly Tukey's tri-cube weight function (Tukey, 1977) is used:

$$w(x) = \begin{cases} (1 - |x|^3)^3 for |x| < 1\\ 0 for |x| \ge 1 \end{cases},$$
(2)

After the obtaining the weights, WOLS regression is performed by the matrix equation:

$$B = (X^T W X)^{-1} X^T W Y, (3)$$

where *X* - matrix with the independent variable in second column and first column set to one;  $X^T$  - transposed matrix of *X*; *W* - square matrix with weights on the diagonal and other elements set to zero; *Y* - vector of the dependent variable; *B* - vector of regression coefficients. Then the vector of predicted *Y* values  $\hat{Y}$  can be expressed as:

$$\hat{Y} = B^T X,\tag{4}$$

where X - matrix with the independent variable in second column and first column set to one;  $B^T$  transposed matrix of B;  $\hat{Y}$  - vector of predicted values of the dependent variable. After the obtaining the predicted 'smoothed' values of the dependent variable from the equations (3) and (4), regression is performed with the equation (1) to calculate the regression coefficients. If several models are employed, Akaike Information Criterion (AIC) (Akaike, 1974) is used. AIC aims to select the model which best explains the variance in the dependent variable with the fewest number of independent variables (parameters). So it helps select a simpler model (fewer parameters) over a complex model (more parameters). AIC measures the information lost, so the model with a lower AIC score indicates a better fit. AIC is calculated by formula:

$$AIC = Nlog\left(\frac{SS_e}{N}\right) + 2K,$$
(5)

where N - number of observations; K - number of parameters;  $SS_e$  - sum square of errors.

#### **Results and Discussion**

The scatterplot with the Balance after treatment as the dependent variable and net turnover before treatment as the independent variable is mapped on 'Figure 1'.



Figure 1. Balance after treatment and net turnover before treatment in treatment and control groups.

As there is a discontinuity in the outcome variable at the cutoff point ( $\notin$ 15000 threshold), the research continues with the construction of several regression models. As

some treatment group members do not receive treatment, Type I fuzzy design is chosen. Similarly with the Balance, discontinuity at the cutoff point can be seen for the other indicators - Productivity, Labour, UAA and Intermediate Consumption. The parametric or global strategy is selected using all observations for the modelling the outcome as a function of the rating and treatment variables. The study uses two specifications of the equation (1) - linear with interactions (m=1) and quadratic with interactions (m=2). Three smoothing parameters are used with values 0.5, 0.33 and 0.16. First, for all four indicators and every specification of the equation and value of the smoothing parameter, weights are calculated by formula (2), WOLS regression is performed by the equation (3) and predicted (smoothed) values of the dependent variable are calculated by the equation (4). Then the regression is performed with the equation (1) to calculate the regression coefficients. After that AIC criterion is calculated by formula (5). The statistically significant values of the ATT (coefficients  $\beta_2$ ) from all 24 models along with respective AIC criterion values are shown in Table 1.

Table 1

Models with statistically significant ATT effects and respective AIC values					
Indicator	Model specification	Smoothing parameter	ATT effect	AIC	
Balance	Quadratic	0.5	2112 (5.09)***	874	
Balance	Linear	0.5	6301 (13.04)***	968	
Balance	Quadratic	0.33	3482 (4.24)***	987	
Balance	Linear	0.33	9191 (12.75)***	1034	
Balance	Linear	0.16	6161 (4.4)***	1144	
Productivity	Quadratic	0.5	1415 (2.85)***	904	
Productivity	Quadratic	0.33	4097 (6.08)***	954	
Productivity	Linear	0.33	1518 (1.95)*	1047	
Productivity	Quadratic	0.16	5502 (2.94)***	1123	
Labour	Linear	0.5	0.09 (8.17)***	-798	
Labour	Quadratic	0.33	0.11 (2.85)***	-651	
Labour	Linear	0.33	0.24 (8.66)***	-644	
Labour	Quadratic	0.16	0.61 (5.37)***	-479	
Labour	Linear	0.16	0.48 (6.23)***	-476	
UAA	Quadratic	0.5	7 (6.33)***	-99	
UAA	Quadratic	0.33	11 (4.37)***	24	
UAA	Linear	0.5	28 (13.82)***	66	
UAA	Linear	0.33	41 (13.63)***	129	
UAA	Linear	0.16	38 (7.93)***	207	
Intermediate consumption	Quadratic	0.5	516 (2.33)**	770	
Intermediate consumption	Linear	0.5	2674 (13.47)***	821	
Intermediate consumption	Quadratic	0.33	5632 (9.16)***	939	
Intermediate consumption	Linear	0.33	7023 (16.22)***	950	
Intermediate consumption	Linear	0.16	3170 (1.74)*	1187	
Intermediate consumption	Quadratic	0.16	5094 (1.81)*	1190	

For the further assessment, values of the treatment effect with the lowest AIC criterion scores are retained. The ATE for four indicators are shown in Table 2.

According to the data of the paying agency, during the entire period of operation of the RDP 2014-2020, the support of the relevant measure has been provided to 3464 beneficiaries. The total impact for each indicator is calculated by multiplying the respective ATE effect by the total number of beneficiaries. Then the average indicators for the farms with the net turnover less than  $\epsilon$ 15 thousand from the FADN data panel are calculated. By dividing the ATE effect with the respective indicator value from the FADN data panel, the shares of the impact in the values of the indicators are estimated at this farm size group level.

	Table 2
Indicator values with the low	est AIC scores
Indicator	ATT effect
Balance	EUR 2 112
Productivity	EUR 1 415
Labour	0.09 AWU
UAA	7 ha
Intermediate consumption	EUR 516

The total number of farms with the net turnover less than  $\notin$ 15 thousand nationwide is 12,270. Then the total national aggregate values for each indicator are calculated by multiplying the respective indicator value from the FADN data panel by the total number of small farms. Finally, shares of the impact in the aggregate indicator values are calculated dividing the total impact for each indicator by the respective total national aggregate values. The results of these estimations are shown in Table 3.

Table 3

Estimated aggregate impact of the support on the economic indicators						
Indicator	Balance (EUR)	UAA (ha)	Intermediate consumption (EUR)	Labour (AWU)	Productivity (EUR/AWU)	
ATE	2 112	7	516	0.1	1 415	
Average for a single beneficiary	9 017	36	16 892	1.4	11 646	
Share of the ATE impact	23%	20%	3%	6%	12%	
Total impact on beneficiaries	7 314 398	25 087	1 787 387	307	1 415	
Aggregate national value	110 638 590	442 898	207 264 840	17 080	10 081	
Share of the total impact	7%	6%	1%	2%	14%	

The most marked estimated impact on the small farms at the 23% level is on the Subsidy and Tax Balance and on the increase in the area of the Utilized Agricultural Area (UAA) (20%) and on the increase in Productivity (12%) which is calculated as Net Turnover divided by full-time employees expressed in Annual Working Units (AWU). Although to a lesser extent, a positive effect at the 6% was also seen on Labour input. This is an important finding, because it proves that the measure also promotes employment in the countryside, at the same time as raising productivity. Due to the expansion of production the value of Intermediate Consumption costs also has increased by 3%. The impact on the increase in intermediate consumption is relatively low if compared to other indicators. This indicates a relatively high efficiency. The shares of the total impact on all small farms nationwide are somewhat lower, except the impact on Productivity at 14%. The shares for the Subsidy and Tax Balance and UAA stand at 7% and 6%, respectively. The positive effect on employment is less than 2% of the total employment in this group of farms. The share for the Intermediate Consumption is the lowest. The efficiency of the support provided by the measure can be estimated by the conditional gains in the indicators against EUR 1 000 of the public funding. The aggregate impact on the indicators at the small farm level is divided by the total cost of the measure (public funding) at EUR 46.4 million. The results of these calculations are provided in Table 4.

There are few studies that evaluate the economic effect of support for small farms in Latvia. Some research has been done in AREI. According to survey data, investment support for small farms has had the most pronounced positive impact on the value of produced and sold products, as well as on long-term investments (Veveris & Puzulis, 2018). A more extensive study is published on AREI website (AREI, 2017).

Table 4 Gains form the € one thousand of support

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Indicator	Gains
Balance	€ 158
UAA	0.54 ha
Intermediate consumption	€ 39
Labour	0.0066 AWU

In this study, various aspects of small farms have been evaluated, including socio-economic ones. The direct impact of supported investments made by small farms has also been assessed using the quasi-experimental methods based on counterfactual, such as Propensity Score Matching and Generalized Propensity Score Matching. A few two-country studies evaluate the impact of RDP on small farms both in Latvia and Lithuania. Four economic indicators were calculated collaboration by Latvian and Lithuanian in researchers: gross farm income per work unit; standard output; gross investment and subsidies on investment per ha UAA. It concludes that changes in trends of subsidies on investment have consequences in income trends of small farms in Latvia and Lithuania (Veveris et al., 2019). The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a method employed for the multi-criteria analysis by Volkov et al. (2019). They have established that from 2013 onwards, changing the principles of the Common Agricultural Policy Direct Payment schemes and payment rates with more support allocated for small and young farmers, the values of the composite indicator for social sustainability has increased in Lithuania. Through the example of small farms from Poland, Romania and Lithuania, it has been shown that financial support of small-scale farms is regarded by the owners as an important element of sustainable development, both from an economic perspective and for the fulfilment of social and environmental functions (Hupkova et al., 2023). Another study that has been conducted in Poland, uses Cluster Analyses and Principal Component Analysis (PCA). This study also confirms the importance of support. It was concluded that the development of small farms is particularly influenced by external factors (EU funding; national benefits), rather than internal (entrepreneurial) factors (Hornowski et al., 2020). Staniszewski and Borvchowski (2020) use FADN data on European regions studying the impact of subsidies on farm efficiency. Their research confirms that the impact of subsidies on efficiency depends on the size of farms. Statistically significant, stimulating effects of subsidies were identified only in the group of the largest farms. Such results put into question the effectiveness of the CAP in stimulating the development of the European Model of Agriculture. Kryszak et al. (2021) also use FADN data in the analysis of the impact of subsidies under the CAP. Albeit they recognize the necessity to ensure adequate profitability for small farms, at the same time considering the challenges that agriculture will face in

the future associated with the climate change and growing demand for food, support mechanisms for the largest farms should be revised. The authors consider their long term viability crucial for the global competitiveness of European agriculture.

#### Conclusions

- 1. According to the calculations, RDP investment support in small farms has a significant positive impact on the production subsidy and tax balance, agricultural land areas and labor productivity.
- 2. Although to a lesser extent, the measure also promotes employment in the supported farms. This has also caused a slight rise in intermediate consumption.
- 3. The impact of support at the national level is estimated at around 1-6% of the total amount of relevant indicators in the small sized farm group.
- 4. The analysis of other studies confirms that the support given to small farms improves both their economic performance and social sustainability. However, differences between small and other farms still remain significant.
- 5. Therefore, it is possible to assess that this type of support is effective and it is useful to make it available to an even larger number of small farms, because currently only part of the farms in the relevant group can use it due to limited funding.
- 6. Further studies are required for the approbation of the method for other rural support measures in order to more detailed estimation of its usability in assessing the impact of support.

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## DEVELOPMENT TRENDS AND OPPORTUNITIES FOR SOCIAL ASSISTANCE

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#### Abstract

A social security system must provide social security and support for all members of society, regardless of their age or financial situation. The elderly and disabled may face various health problems, physical and mental decline which may make them dependent on other people or on professional care. People with financial means lack the care they need; for example, older people who may not have family carers or who do not want to use commercial care services. In this case, an additional support system is needed to provide care for those with financial resources. A social program should be available so that these people can receive help from the state or the municipality. As life expectancy increases and older people become a larger demographic group in society, it is essential to provide adequate care and support for this group of older people. This includes medical and health care, as well as social care and emotional support. In this context, the state and society have a responsibility to provide appropriate care services and resources to ensure the dignity, comfort, and security for older people if they can afford private care. In old age, people deserve to live with dignity and quality care, regardless of their financial situation or social status. This requires care and attention by both the state and society to establish and maintain systems that guarantee that the needs of older people are met.

Key words: social services, social policy, social development.

#### Introduction

The relevance of social care services is determined by the importance of using the latest quality technologies and tools for social services, adapted to the country's internal economic conditions.

Historically, in Soviet times, social services were provided within the social security system in inpatient state institutions: nursing homes, orphanages, psychoneurological centers, boarding schools, etc. Their aim was to provide assistance to those categories of the population who could not live independently, who were unable to care for themselves. Many of them were severely disabled.

In the early 1990s, the number of people in need of social assistance and support soared. New groups were emerging in the social fabric of society: the poor, the disadvantaged, the homeless, victims of domestic violence, etc. This has forced state and local authorities to rethink the role of social services in people's lives and to change the system of service provision.

To meet the objective needs of the population for social services, networks of national and local authorities were set up to provide specialized social assistance, which made it possible to set up the current system of social services for the population.

Theoretical understanding of the relationships that are emerging in this field, the need to assess changes in the regulatory, resource and financial framework, and the need to prioritize social service provision are important.

Social services have been explored in the work of several experts, for example, Marla Berg-Weger and Linda K. Grobman provide a comprehensive introduction to the field of social work and social services, outlining their nature, history, values, and ethics (Marla Berg-Weger, 2019).

Researchers Jillian A. Jimenez, Jodi L. Jacobson, and Eileen Mayers Pasztor examine the role of social policy and social services in building and ensuring social and economic justice (Jimenez *at al.*, 2014). Experts Diana M. DiNitto and David H. Johnson provide insights into social services policies and activities aimed at promoting social justice and wellbeing in different policy areas (Jansson, 2015). Economists Ralph Dolgoff, Donald Feldstein, and Linda Deutsch offer an explanation of the concept of social welfare, social risks and strategies to address them, including the role of social services in this process (Dolgoff & Feldstein, 2006).

#### Materials and Methods

Researchers John Dixon, Bob Pease, and Bill Fredericks explore future trends and challenges in social services and their role in today's society. There are many more examples of researchers who have explored the field of social services and future trends. There is a wealth of research and literature that offers a deeper understanding of social care services and social assistance, their nature and role in society, as well as the history of their development and an analysis of existing systems.

*Social care* is a broad concept that encompasses a range of care and support activities provided to people with different needs to ensure their well-being and quality of life (Jordan, 2012).

This includes both physical and psychological care services, as well as social and emotional support (Vickerstaff, 2011). Social care can be provided in the home or in an institutional setting, depending on the client's needs and situation (Giddens, 1998).

*Social services* are the various forms of support and assistance provided to individuals or groups to improve their well-being and ensure their integration into society (Vourlekis, 2014). These services can include education, health, employment, housing, and other forms of support provided to make life easier and to address social and personal challenges (Doel & Shardlow, 2005; Adams, 2009).

*Social assistance* is a system that provides financial support, resources, and services to people with low incomes or other social risks to ensure their basic needs and well-being (Popple & Leighninger, 2018).

This can include cash benefits, free or reduced health and education services, and other forms of assistance (DiNitto, 2007).

The state is responsible for social stability in society. The state regulates the main parameters of the socioeconomic development of socie ty, implements social reform strategies and social programs. National social models are an important aspect of political and sociological research, and their classification may vary according to different criteria. However, they can often be classified according to their respective main characteristics or priorities, e.g. the role of the state in the economy, social welfare, employment, etc. Let us mention the most popular theoretical models of welfare states.

#### Directions for social services

A liberal welfare state is a state whose social policies are based on liberal ideas and principles. A liberal welfare state is a model of state that guarantees the maintenance of a minimum income and relatively high quality social and medical services, education, support for the elderly and disabled, and housing and public utilities for the population. Examples include Australia, Canada, Japan, Switzerland (Galbraith, 1998).

#### Conservative welfare state

A conservative welfare state is a state whose social policies are based on conservative ideas and principles. This type of state places great emphasis on tradition, individual responsibility and the private sector, minimizing state intervention in the economy and social life, and offering limited, moderate social support to the people. The welfare state model is embodied, for example, in Anglo-Saxon countries such as the United Kingdom and the United States (Barr, 2001).

*The Nordic model* is characterized by a high level of social welfare, a broad social security system and a high tax burden (Korpi & Palme, 1998). *The main features of the Continental model* are widespread state intervention in the economy, an extensive social security system, but less emphasis on labor market flexibility (Palier & Thelen, 2008).

Corporate welfare state. In this model, the state takes responsibility for the welfare of its citizens, but at the same time delegates a significant part of its social responsibilities to the private sector, actively forcing it to participate in the implementation of all state social programs. Under these conditions, a significant part of the social care of their employees is borne directly by the companies and organizations themselves: they pay for advanced training, run their own pension schemes, and pay for medical and other social services. A corporate welfare state is one in which the state and business are closely intertwined, and in which economic development and social welfare are provided primarily by private companies, often with corporate interests as a priority. In this type of state, state intervention in the economy is minimal and corporations often use state resources and policies to protect their interests (Fuchs, 2007).

This model has been successfully implemented for many decades in Austria, Belgium, France, Germany, Italy, Ireland, and the Netherlands.

The main features of the Anglo-Saxon model are a low tax burden, less state intervention in the economy and less emphasis on social security (Hall & Soskice, 2001). The Anglo-Saxon concept of the minimal state, often referred to as liberalism or the liberal market economy, emphasizes limited state intervention in the economy and in public life. This type of state seeks to ensure market freedom, individual liberty and entrepreneurial opportunities by minimizing state regulation and social support (Friedman, 1962). The Latin American model is characterized by low levels of social security, high levels of social inequality and unequal access to health and education services.

In a social-democratic welfare state, citizens have equal opportunities to satisfy their material, cultural and spiritual needs, to realize their value orientations and social attitudes. In this context, the State guarantees civil, political, economic, and social rights, considering that the convergence of income and life chances is the main material and legal condition for everyone's freedom. Its guiding principle is the priority of citizens over the state and economic performance. Social public policy is the immediate, direct responsibility of the state.

A social democratic welfare state is one in which the ideas and principles of social democratic politics are central to economic and social policy - making. In this type of state, the state intervenes heavily in the economy and in public life to ensure broad social support, the promotion of equality and the provision of welfare for all members of society.

This welfare state model has been introduced in several Scandinavian countries, mainly Denmark, Norway, and Sweden (Hilson, 2008).

## The traditional French model

The traditional French model refers to the French political and economic system, which has developed based on specific ideas and values of French origin. This model involves a high degree of state intervention in the economy and in public life to ensure broad social protection and equality (Powell, 2009). It is oriented towards full support for independent initiatives, entrepreneurship and any ability of individuals and groups to meet their own needs, while the interests of groups and communities prevail over those of individuals or companies as such: the German model is based on the priority of social interests (group, regional, national) over economic interests. The German or Rhine model of public administration is very specific and different from those of other countries. Germany's federal system and governance structure is complex, encompassing both federal and regional levels, and it has a rich history and culture that shape its specific governance model. This model is relevant for the study of both German and European politics and governance (Conradt & Lindenbacher, 2013).

#### **Results and Discussion**

The impact of social care on the public budget is significant, as social care services are provided through public funding or public expenditure. This impact can be positive or negative and is determined by many factors, including the type of public social care policy, demographic trends in the population and

#### the economic situation.

The cost of social care services is significant. The state must provide funding to cover the costs of social care services, such as home care for the elderly, institutional care, care for the disabled and other forms of support. This expenditure can be a significant item in the national budget (Statista, 2021), see 'Figure 1'.





Figure 1. Chart: Statistics data where social spending is highest and lowest (Statista, 2021).

The growing number of older people and other factors can affect the tax revenue needed to finance social care. Government budget revenue and expenditure can have a significant impact on public funding for social care programs.

National policy - making and changes to social care programs can have implications for the national budget, such as cost increases or reductions in line with new program rules and priorities.

A favorable social care policy can contribute to

increasing economic and social well-being in society, thereby reducing other social costs such as unemployment benefits or medical costs.

Investing in social care programs can bring long-term benefits such as improved health outcomes, reduced poverty and sustained economic growth.

Let's look at the cost of social services as a % of GDP. The cost of social services in Latvia in 2021 was 19.1% of real GDP (Eurostat, 2023), see 'Figure 2'.



# DEVELOPMENT TRENDS AND OPPORTUNITIES FOR SOCIAL ASSISTANCE



Figure 3. Chart: Social protection - Social spending - OECD Data (OECD.org, 2019).

It is difficult to clearly identify which country has the most 'modern' social care and services for its citizens, as this may depend on various factors and criteria, such as available resources, policies, and societal priorities (OECD, 2019). However, some countries are generally considered to be advanced in terms of social care and services, see 'Figure 3':

**South Korea:** South Korea has one of the highest standards of living and modern social care systems. The country has introduced many innovative solutions such as remote healthcare and digital health services.

**Denmark:** Denmark is known for its welfare system and social security, which includes high quality healthcare, education, and social care. Denmark is often considered one of the best countries to live and work in.

**Switzerland:** Switzerland is known for its high standard of living and modern social systems. The country offers a wide range of health and social services and has high health and quality of life indicators.

**Sweden:** Sweden is known for its progressive social policies and extensive social provisions, including healthcare, education, and care services for the disabled and the elderly.

**The Netherlands:** The Netherlands is one of the countries with a high standard of living and an advanced social care system. The country offers a wide range of health and social services, including care services and solutions for ageing.

These are just a few examples, and it is worth noting that many other countries have also introduced innovative and modern social care systems, depending on their needs and capacities. Each country may have its own strengths and weaknesses in social care and services, so it is important to carefully explore and compare the different options available. These are just some of the factors that determine the impact of social care on public budgets (Colombo, 2011). To fully understand this issue, more research and analysis of country-specific situations and policies are needed.

#### Social care and services in Latvia

**Latvia** has a growing elderly population and demographic changes, such as longer life expectancy, affect the demand and need for social care. There is a

need for a shift towards home care and telehealth, considering people's preferences and the need to stay at home, considering individual needs and preferences. Recently, there has been an increase in the cost of social care in the national budget, as funds are needed to provide care services and payment for staff. Investing in social care can bring long-term benefits. Evaluating the effectiveness of social care policies and programs to ensure efficient use of resources and better management of the public budget should be carried out.

Next, let's look at social services for the elderly. In the social sphere, older people can face many problems and challenges that affect their well-being, health, and quality of life, such as social isolation. In old age, people may feel isolated from the society, especially if they live alone or have lost their social networks. As people age, their physical health may deteriorate, and they may experience mobility problems that limit their ability to move around and care for themselves.

Lack of pensions and other financial resources can make it difficult to pay for basic living expenses, including housing, food, and medical care.

Depression, anxiety, and other emotional problems can occur in old age, especially if people are facing losses such as losing a partner or friends, or health problems. For a variety of reasons, older people may find it difficult to access the healthcare and social services they need. Sometimes older people may lack the support they need from family or carers, which can lead to feelings of isolation and make everyday life more difficult. These problems can affect older people's wellbeing and quality of life, and it is therefore important to develop and offer appropriate social services and support to help address these problems and improve their lives.

*Modernizing social services for older* people is an important and necessary process to ensure their wellbeing, self-determination, and participation in society. Here are some suggestions on how these services could be modernized:

*First*, by introducing and offering simple and userfriendly digital technologies for older people, such as mobile apps, web platforms or video conferencing to enable remote access to healthcare, social networks, and counselling.

*Second*, by offering educational courses and training. Providing opportunities for older people to learn new skills and knowledge, such as digital skills or basic healthcare knowledge, which can help them maintain their independence and improve their quality of life.

*Third*, mobility solutions. Developing and offering tailored transport solutions, such as shared transport services or improved public transport services to enable older people to move around easily and participate in social life.

*Fourth*, by setting up centers and various activity programs. Creating local centers and organizing various social and physical activities suitable for older people to promote social interaction, physical activity, and spiritual development.

*Fifthly*, personal care services. Developing flexible and tailored personal care services that meet the individual needs of older people and provide access to quality and empathetic care and support.

*Sixth*, developing information and advice services. Providing accessible and understandable information on available social services, entitlements, and benefits, and offering advice and support to enable older people to better understand and use their options.

*Seven*, by attracting public support and cooperation. Building partnerships with local business and community organizations to jointly develop and deliver social services that meet the needs and interests of older people.

The average age of the Latvian population is steadily rising, and the population in different regions of the country, urban and rural, is ageing unevenly, but the general trend of a high proportion of older people in the overall structure of the Latvian population will continue in the long term.

An ageing population goes hand in hand with declining health among older people. Morbidity and mortality rates are high for the elderly and seniors.

The formal and informal resources for social services, the criteria for assessing the need for services and the modernization of society's social sphere also have an impact on the development of the need for social services. Sociological studies confirm the increasing need of the population for social services. This is due, on the one hand, to the increase in the number and proportion of people in need and, on the other, to the expansion of the range of services.

## Conclusions

- 1. The lives of all segments of the population depend on conditions determined by the level of development of society, the state of the social sphere, the content of social policies and the possibilities of their implementation.
- 2. Ensuring the state approach to social work in practice implies the ability to analyze and identify socio-political development trends in public life, as well as to determine the most realistic and effective ways of solving problems in the social sphere.
- 3. The development of modern society, the predominance of new forms of interaction, the redistribution of powers and the modernization of the social and administrative apparatus are determined by the following factors:
  - dissatisfaction with the financial situation of crisis segments of the population,
  - the public demand for new social policies,
  - the problematic development of the social services system.
- 4. The modernization of principles, mechanisms and management decisions in social services, the development of the service system is linked to the need to consider new trends related to the institutionalization of social services, the creation of a single interdisciplinary space, the coordination and complementarity of the main functions of institutions, the universalization of interinstitutional norms in the context of the modernization of the social sphere.
- 5. Innovative social service technologies are used to meet the needs of the population and provide real assistance in the process of adaptation, rehabilitation, correction, and socialization. They extend the range of social services, improve their quality and efficiency, contribute to the activation of the individual's essential resources, and develop productive behavioral skills in complex life situations.

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# PARADIGMS OF THE DIGITAL ECONOMY AND SOCIETY: A COMPARATIVE ANALYSIS OF LATVIA AND LITHUANIA

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#### Abstract

Digital progress in the European Union is a catalyst for economic development. The COVID-19 pandemic significantly accelerated the pace of digitalization, thereby creating not only challenges for the European Union but also new opportunities for economic development in Europe. The present research focuses on an analysis of digital economy and society index scores for Latvia and Lithuania, comparing the performance of both countries with the European Union average. The research aims to identify the critical areas that hinder digital progress in Latvia and Lithuania. Accordingly, the digital economy and society index was analysed for the period from 2018 to 2023. The empirical part of the research includes a sociological survey, and the survey data were analysed in order to identify population needs for and experience in using digital technologies in Latvia and Lithuania to focus on for further digital progress. Latvia and Lithuania both show high scores, well above the EU average, in the 'digital public services' component, indicating that both countries have a high level of e-government users and widespread access to digital public services. The results of the sociological survey further confirm this, showing that a large majority of 84.25% of respondents in both Latvia and Lithuania use digital solutions in their daily lives. **Keywords:** DESI, Digital society, Digital economy, Baltic States.

#### Introduction

The problem of interaction between digitalization and society has been relevant since the 1970s. Robert Wachal was the first author to use the term digitalization of society in his writings in 1971 (Sept, 2020). It could be said that the beginning of the 1970s was significant as the initial stage of the integration of information technology, while at the end of the 1990s, the increasing pace of information technology progress caused a global transformation (Česnauskė, 2019). It should be highlighted that the positive impact of digitalisation on the economy has been discussed in several forums in Europe. These included the Trade Union Advisory Committee in 2017, which focused on new technologies, knowledge and skills. The Stakeholders Forum, held in 2018, highlighted the need for Europe and industry to become digital in the future (Rivža et al., 2019).

Besides, the opportunities and challenges of digitalization constantly change. The COVID-19 pandemic created countless challenges, yet it also gave new opportunities to increase the pace of digitalization (Almeida, Duarte Santos & Augusto Monteiro, 2020). In addition, the digital progress in the European Union (hereinafter referred to as the EU) had high expectations for economic development. This means that the digital progress would accelerate digitization processes at the public and private level through combining resource and cost optimization. At the same time, it would increase the competitiveness of the economy and reduce public costs. Accordingly, Europe and the world could be expected to be marked by the development of advanced technologies in the future (Troitiño, 2022). Europe aims to move towards a sustainable and prosperous digital future. The Digital Decade path is a programme that contributes to the digital transformation in Europe and sets out four main policy areas for 2030: digital skills, company digital

transformation, secure and sustainable digital infrastructure, public service digitalization (European Commission, 2023). Therefore, employing the digital economy and society index (hereinafter referred to as the DESI), the European Commission monitors the digital progress in the 27 Member States of the EU (European Commission, 2022). The DESI index allows assessing the digital competitiveness of the EU Member States. It aims to identify areas where additional investment is needed to digitalize the economy and society (Sevgi, 2021). It can be said that since 2014, the European Commission publishes annual reports on Member States' digital progress and detailed analysis of indicators covering internet usage, e-commerce usage, e-government, etc. (Brence, Gudele, & Rivža, 2022).

However, the main question is whether Latvia and Lithuania are ready for digital changes. The research aims to identify the critical areas that hinder digital progress in Latvia and Lithuania. Based on sociological research, identify the experiences and needs of the society in Latvia and Lithuania in using digital solutions.

#### Materials and Methods

The research employed the monographic and descriptive methods to identify relevant research studies and findings and make a theoretical discussion. Statistical data analysis was employed to achieve the research aim. DESI index scores for Latvia and Lithuania were qualitatively and critically analysed and compared with the EU average. The research identified critical areas in digital progress in Latvia and Lithuania. The research period was 2018-2023. The DESI index scores were analysed based on equal weights for 4 dimensions: human capital 25%, connectivity 25%, digital technology integration 25%, digital public services 25% (European Commission, 2022).

At the same time, the research analysed the results of the sociological survey. The survey was conducted with the aim of identifying population needs for and experience in using digital technologies in Latvia and Lithuania. The survey period was September 2023 -December 2023, involving a total of 146 respondents. As a result, 83 respondents from Latvia and 63 respondents from Lithuania answered 9 questions in person, using both Likert scales and closed-ended multiple-choice questions from which one or more answers had to be selected. IBM SPSS (SPSS Inc., 2016) software and descriptive statistics were used to analyse the data, which revealed the respondents' experience in and their needs for using digital technologies. At the same time, the Cross tabulation tool was used to gain a deeper understanding of the survey results, parametric methods T-test, F-test were used to compare the samples.

#### **Results and Discussion**

To identify the critical areas in digital progress in Latvia and Lithuania, the research analysed DESI index scores for the 27 Member States and performed a component analysis.

As explained above, the DESI Index is a tool used since 2014 to measure and monitor the digital economy and society in Europe. It consists of 4 components focusing on the digital goals of the European Digital Decade (Kovács *et al.*, 2022).

The analysis of DESI index scores for EU Member States in 2022 (European Commission, 2022) revealed that among the 27 Member States, Latvia ranked 17<sup>th</sup> with a score of 49.7, which was lower than the EU average score of 52.3. At the same time, Lithuania ranked 14<sup>th</sup> with a score of 52.7, being at a higher position. Overall, the leader in digital progress, according to the DESI index 2022, was Finland, which ranked 1<sup>st</sup> with a score of 69.6, while Romania had the lowest score of 30.6.



Figure 1. DESI index scores for Latvia, Lithuania and the EU-27 from 2018 to 2022.

Source: authors' construction based on European Commission, (n.d.).

The analysis of DESI index scores (European Commission, n.d.) for the period 2018-2022 'Figure 1' revealed that in 2022 compared with 2018, the DESI score increased by 6% for Latvia, 7% for Lithuania,

while the EU average increased by 12%. In addition, the largest decrease in DESI scores was observed during the COVID-19 pandemic, and in 2021 compared with 2020, the DESI score decreased by 4% for Lithuania, 2% for Latvia and the EU average decreased by 4%.

The analysis of DESI scores by component has revealed that the 'Human capital' component includes such indicators as digital skills at the basic level and above the basic level, ICT specialists and graduates, as well as companies that provide ICT training etc. (European Commission, 2022).

The analysis of performance (European Commission, n.d.) in the period from 2018 to 2022 'Figure 2' revealed that the 5-year average score was 40.12 for Latvia, 43.06 for Lithuania, and the EU average was 47.52.



Figure 2. DESI index scores for the 'Human capital' component for Latvia and Lithuania and the EU-27 from 2018 to 2022.

Source: *authors' construction based on European Commission*, (*n.d.*).

It should be mentioned that in 2020 Latvia shows a significant decline in the component of indicators such as digital skills at and above the basic level, ICT specialists. Lithuania, on the other hand, shows moderate progress in the component since 2018, but in 2022 there is a drop in the indicators at least basic digital skills and above basic digital skills. The scores for the 'Human capital' component in 2022 (European Commission, 2022) show that Latvia with 44.1 and Lithuania with 42.5 did not reach the EU average of 45.7. Latvia ranked 18th and Lithuania was 20th among the 27 Member States. A detailed analysis of scores in 2022 revealed that Latvia had a higher score of 51 than Lithuania with 49 but lower than the EU average of 54 for the indicator 'digital skills at the basic level'. The indicator 'ICT specialists' had the same score for both Latvia and Lithuania at 3.8%. However, it was lower than the EU average of 4.5%. In the indicator 'companies that provide ICT training', Latvia with a score of 17 was ahead of Lithuania with a score of 14, which was a much lower performance compared with the EU average of 20. Although Latvia and Lithuania had higher scores than the EU average for the indicators 'ICT graduates' and 'ICT specialists', the overall score for the 'Human capital' component did not reach the EU average level in 2022.

An analysis of DESI index scores for the 'Connectivity' component has revealed that it includes such subcomponents as fixed broadband take-up, 5G coverage, mobile broadband take-up etc. (European Commission, 2022). The analysis of performance for the period from 2018 to 2022 'Figure 3' revealed that the 5-year average score (European Commission, n.d.) for Latvia was higher at 55.02 than for Lithuania at 45.9, while the EU average was 48.96. Although Latvia had a score well above the EU average and Lithuania showed an upward trend in 2020, the year 2021 decreased the scores for both countries. The analysis of scores for the 'Connectivity' component in 2022 (European Commission, 2022) revealed that Latvia had a higher score of 50.1 than Lithuania with 49.4; however, both countries did not reach the EU average of 59.9. Among the EU-27, Latvia had 20<sup>th</sup> position, Lithuania had 23<sup>rd</sup> position. A detailed analysis of the indicator 'at least 1 Gb/s take-up' revealed that Latvia had a score of <0.01. Lithuania had a score of 0.72, which were critically low compared with the EU average of 7.58. At the same time, Latvia had a critically low score of 0 for '5G coverage', while Lithuania had a much higher score of 33, which however did not exceed the EU average score of 66. It should be noted that Lithuania with a score of 5 was significantly behind the EU average of 56 for the indicator '5G spectrum', which was less challenging for Latvia.



Figure 3. DESI index scores for the 'Connectivity' component for Latvia and Lithuania and the EU-27 from 2018 to 2022.

Source: *authors' construction based on European Commission*, (*n.d.*).

The analysis of the 'digital technology integration' component of the DESI index has revealed that it includes such sub-components as digital transformation of small and medium enterprises (hereinafter referred to as SMEs) at the basic level, SMEs using e-commerce, cloud services etc. (European Commission, 2022). The analysis of performance for the 'digital technology integration' component in the period from 2018 to 2022 'Figure 4' revealed that the 5-year average score (European Commission, n.d.) for Latvia was 26.04, 44.28 for Lithuania and the EU average was 38.54. The scores for 2022 showed that Latvia had a score of 25.8, which was significantly lower than a score of 37.2 for Lithuania and the EU average of 36.1. Lithuania ranked 13th and Latvia 23rd among the EU-27. A

detailed analysis revealed that Latvia had low scores in almost any sub-component, including 'SMEs with digital intensity at least at the basic level'; Latvia had a score of 38, compared with the EU average of 55 and a score of 57 for Lithuania. In Latvia 15% used einvoices, 27% in Lithuania, and 32% on average in the EU. It could be said that Latvia with a score of 14 has a problem with 'SMEs selling online', while Lithuania had a score of 32, which was much higher than the EU average of 18%.



Figure 4. DESI index scores for the 'digital technology integration' component for Latvia and Lithuania and the EU-27 from 2018 to 2022.

Source: *authors' construction based on European Commission, (n.d.).* 

The 'digital public services' component includes such sub-components as open data, e-government users, ehealth etc. (European Commission, 2022). An analysis of performance for the component 'digital public services' in the period from 2018 to 2022 'Figure 5' revealed that the 5-year average score (European Commission, n.d.) for Latvia was 79.64, 79.44 for Lithuania and the EU average was 67.24. It should be noted that in 2022, Latvia with 78.8 and 11<sup>th</sup> position and Lithuania with 81.8 and 10<sup>th</sup> position showed a similar performance among the EU-27, which was higher than the EU average.





Source: *authors' construction based on European Commission, (n.d.).* 

The scores for the component in 2022 showed that Lithuania had significantly higher scores of all the indicators, while the performance of Latvia was slightly poorer but remained well above the average. A more detailed analysis revealed that Lithuania had a score of 70 for the indicator 'e-government users', while Latvia had a score of 84. Lithuania had a higher score of 93 than Latvia with 86 for the indicator 'digital public services for companies'. However, Latvia had a higher score of 87 than Lithuania with 82 for the indicator 'digital public services for individuals'.

The 2023 Digital Decade report should be considered to draw conclusions about digital progress in Latvia and Lithuania. According to the report, Latvia had high scores for the indicators 'digital public services' and 'fixed connectivity'. It should be stressed that there was insufficient growth in 5G coverage, as well as in business digitalization. Lithuania, however, had high scores for 'digital public services', while digital skills have increased significantly. To achieve the goals of the Digital Decade, according to the report, the scores of indicators of the 'connectivity' component must be higher (European Commission, 2023).

It should be mentioned that in the period from 2014 to 2018, the DESI index scores for both Latvia and Lithuania increased, Lithuania had a higher DESI than the EU average, whereas Latvia had a lower DESI. Accordingly, progress was observed in the areas of connectivity, internet usage and digital public services. In relation to this, J. Česnauskė pointed out that the Baltic States, including Latvia and Lithuania, did not fully use the potential of digital technologies (Česnauskė, 2019).

To make effective business decisions, organizations conduct research in several ways, including finding out the opinions of the public about the services and the products sold. It could be said that one of the most reliable and effective research methods is a survey (Questionpro, n.d.). Accordingly, a sociological study was conducted in Latvia and Lithuania to identify population needs for and experience in using digital technologies. A total of 146 respondents participated in the survey: 83 from Latvia and 63 from Lithuania, aged between 18 and 65, incl. 101 women and 45 men. The survey established that most of the respondents, 84.25%, used digital solutions and technologies daily, 9.59% used them several times a month, while 6.16% used them rarely. Analysing the answers to the question how often you use digital solutions and technologies in your daily life, it was found that based on the results of cross-tabulation analysis, it can be said that the vast majority of respondents in Latvia 79.5% and Lithuania 90.5% use digital technologies on a daily basis and only 13.3% respondents in Latvia, 4.8% in Lithuania use digital technologies only several times a month. However, 7.2% of respondents in Latvia and 4.8% in Lithuania answered that they rarely use digital technologies. Based on the chi-square test results the authors found that since  $\chi^2 = 3.56 < \chi^2_{0.05}$ =5.99, df=2, Sign=0.16 n=146, there are no statistically significant differences between the answers to the given question in Latvia and Lithuania. The answers to a question of which digital solutions and technologies offered by the municipality they used daily (multiple answers were possible), the majority (78.08%) admitted that they used e-services, 66.44% used social media accounts, 64.38% used e-commerce websites offering online purchase of goods and services from local producers, 54.79% had digital cards, while 50.68% admitted that they used eeducation services daily. According to the results of the cross-tabulation analysis, the respondents in the two countries have different answers to the question what digital solutions and technologies are used in their municipality. In Latvia, the largest majority of respondents, 79.5%, indicate that they use e-services in their daily work, while in Lithuania the result is 76.2%. In Lithuania, the largest majority of 77.8% of respondents use municipal social media accounts, while the Latvian result is 57.8%. Based on the chisquare test results, the authors found that since  $\chi^2 > \chi^2_{0.05}$ , the null hypothesis can be rejected and the answers to the question differ significantly between Latvia and Lithuania.

The respondents were asked to rate on a scale from 1 (unimportant) to 10 (very important) the importance of digitalization in their municipalities. In Latvia, the average rating was 9.01, variance - 2.01, in Lithuania - 9.11, variance - 1.42. The variances of ratings are statistically different in Latvia and Lithuania, as indicated by the results of the F-test (see Table 1.): F = 0.707 > F Critical = 0.670, Sign = 0.077.

Table 1

Table 2

F-Test: Two-Sample for Variances

	LT-5	LV-5
Mean	9.111	9.012
Variance	1.422	2.012
Observations	63	83
df	62	82
F	0.707	
P(F<=f) one-tail	0.077	
F Critical one-tail	0.670	

Source: author's construction based on survey results.

On the other hand, there is no statistically significant difference between the average ratings, as indicated by the results of the t-test (see Table 2): t = 0.457 < t Critical = 1.976, Sign = 0.647.

<b>T-Test:</b>	Two-Sampl	e Assuming	Unequal	Variances
I ICDU	I no bumpi	c rissunnig	Unicqual	i un nunceo

	LT-5	LV-5
Mean	9.111	9.012
Variance	1.422	2.012
Observations	63	83
Hypothesized Mean Difference	0	
df	142	
t Stat	0.457	
P(T<=t) one-tail	0.323	
t Critical one-tail	1.655	
P(T<=t) two-tail	0.647	
t Critical two-tail	1.976	

Source: author's construction based on survey results.

The survey results showed that 84.25% of the 146 respondents in Latvia and Lithuania use digital solutions and technologies on a daily basis. In addition, with a mean value of 9.1 (on a scale of 1 to 10), respondents consider digitisation in municipalities to be of high importance.

#### Conclusions

- 1. Digital developments are raising high expectations for economic development. In Europe, digital transformation is taking place in four key areas: digital skills, digital transformation of businesses, secure and sustainable digital infrastructures, and digitisation of public services.
- 2. The results of the study show that the DESI index score in 2022 compared to 2018 has increased by 6% in Latvia, by 7% in Lithuania and by 12% on average in the EU Member States. Latvia and Lithuania are only partially exploiting their digital potential.
- 3. Latvia has had a challenging COVID 19 period. The 2020 results show a significant weakening of the 'human capital' component indicators such as digital skills, ICT specialists. 2021 weakened Latvia's score in the component 'connectivity'.

Thus, a critically low indicator for Latvia is 5G coverage, at least 1 Gbps take-up. Latvia scores critically low in the component 'integration of digital technologies', which has a significant impact on the digitalisation of business.

- 4. Lithuania has improved its score in the 'human capital' component on digital skills since 2018, but in 2022 the score has dropped significantly and is below the EU average. In 2021, Lithuania's score in the component 'connectivity' weakened. Thus, the low score for Lithuania is 5G spectrum, at least 1 Gbps take-up.
- 5. Latvia and Lithuania both show high scores, well above the EU average, in the 'digital public services' component, indicating that both countries have a high level of e-government users and widespread access to digital public services. The results of the sociological survey further confirm this, showing that a large majority of 84.25% of respondents in both Latvia and Lithuania use digital solutions in their daily lives. In addition, respondents in both Latvia and Lithuania rated the development of digitalisation in municipalities as very important.

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## NAVIGATING VULNERABILITIES: SOCIOECONOMIC DYNAMICS AND RESILIENCE STRATEGIES IN SOUTH ASIAN AGRICULTURE

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#### Abstract

This study explores the impact of climate change, social capital, and gender differences on the resilience of smallholder farmers in South Asia. Analyzing data from Bangladesh, India, Nepal, and Pakistan from 2000 to 2020, the researchers have found that climate change significantly reduces agricultural productivity, while social capital acts as a crucial support mechanism. The paper summarizes gender-sensitive interventions in the improvement of adaptive ability and equality in the agriculture sector. It describes innovative farm-level practices and policy measures at various levels to strengthen resilience from environmental challenges. This approach gives room for researchers to find how the elements of climate change, put together with social capital and gender disparities, influence agricultural resilience. The present analysis recaps gender-sensitive interferences aimed at improving adaptive ability and equality in the agriculture sector, describing ground-breaking farm-level performs and policy measures to strengthen resilience against environmental tasks. Data shows that the climate change has a negative impact on agricultural output; therefore, any rise in temperature, change of precipitation, and extreme weather events worsen susceptibility. Social capital is also an essential part in resilience, being a source of resources, information, and support networks that can be drawn on. It calls for the interaction with the opposite gender and gender-sensitive interventions that increase adaptive ability and equality between men and women in agriculture. This study reveals that agri-diversification is pivotal for conservation agriculture enhancing climate resilience in South Asia.

Key words: South Asian agriculture, resilience strategies, climate change, social capital, gender dynamics.

#### Introduction

Agriculture in South Asia sustains millions of smallholder farmers but faces threats from climate change, including rising temperatures, erratic rainfall, droughts, floods, and extreme weather events. These changes reduce agricultural productivity, leading to food insecurity and economic instability. Social capital plays an important role in enhancing agricultural resilience by providing the resources, information, and support services that farmers can obtain from their social networks and relationships, and the shared norms and values that allow them to cope with climatesensitive changes and recover from devastating shocks. Again, gender determines the outcome in terms of agricultural resilience. Gender imbalances in resource access and information and decision-making function as limiting factors that, in turn, limit the contribution to and benefit from the resilience effort. Resilience efforts must be gender-responsive to bring about equal participation and benefit sharing and, by so doing, increase the overall adaptive capacity. Against this backdrop, the current study investigates the impact of climate change and social capital on gender difference among smallholder farmers' resilience in South Asia. It identifies effective strategies of resilience, examines the interplay between social capital and gender, and based on the produces recommendations findings, policy supporting smallholder farmers' livelihoods. The paper will conduct both the descriptive analysis method and inferential statistics. This paper uses Bangladesh, India, Nepal, and Pakistan data from 2000 to 2020 and gives a descriptive analysis of the socioeconomic dynamics and resilience strategies of the smallholder farmer from South Asia and practical measures for enhancing agricultural resilience in the face of climate change.

Concern of livelihoods and food security of millions of people who are working under the agriculture sector in South Asia (Rasul, 2021). This highlights the impact of climate change that can result in the increase in temperature, erratic rainfall, drought and flood occurrences, cyclones, pests, and diseases. These impacts may include issues in productivity, profitability, and sustainability in agricultural production systems, to small-scale farmers who lack resources and adaptation. The realization of increased adaptation and mitigation potentials, which supports resilient and sustainable agriculture by farmers, is a must-do to keep up with meeting the problems posed by climate change. However, adoption of these practices depends on several socioeconomic factors such as social capital, gender, income, education, access to information, access to credit, access to markets, and access to extension services. Understanding how these factors affect the adoption and impacts of climate-resilient agriculture is paramount when designing and operationalizing policies and interventions which could support farmers and enhance their livelihoods (Sinclair et al., 2019; Pilvere et al., 2022).

All of these results which exist in the form of damage to the world in the shape of an altered global climate overall highlights the higher temperatures, melted ice, and a higher level of the sea, and more extreme weather events (Kumar, Ranjan, & Verma, 2021). It necessitates building resilience, reduction of emissions, and sustainable promotion. The World Bank outlines six principles that a climate-resilient building should consist of: development, risk management, planning, flexibility and learning, collaboration, and alignment, as well as empowerment and the protection of the vulnerable.

Specifically, such strategies can be ensuring the delivery of basic services, applying climate risk

information, investing in infrastructure that is resilient and low-carbon, innovations, and diversification of livelihoods, strengthened governance and institutions, enhanced participation, and cooperation, reducing vulnerability and inequality. Thus, these offer space for creative transformation and innovation, allowing social change and resilience to take place and move people towards a more sustainable and resilient future. Social capital has a benefit from these strong social networks, which allows people to either cope or rise above pressing challenges, such as the COVID-19 pandemic (Jean-Baptiste *et al.*, 2020).

Considerable risk was explored by Hoegh-Guldberg and co-authors (Hoegh-Guldberg *et al.*, 2019) that shows any 1.5 °C increase above pre-industrial levels with emphasis on agriculture, according to IPCC. Developing countries including India face more complex challenges such as overburdened food system, intensive pressure on the land and impediments to poverty eradication (Grindle, 2004; Misselhorn *et al.*, 2012). The literature projects a decrease in India's net revenue by 9–25% with a temperature rise of 2–3.5 °C, severely impacting smallholders. To mitigate local climate-related risks, understanding livelihood vulnerability drivers becomes crucial (Shackleton, 2018; Shinbrot *et al.*, 2019).

The term resilience was studied and originated by (Linkov & Trump, 2019) in physics and engineering, denoting a system's capacity to revert to a normal state. It was later introduced to describe a system's ability to absorb changes and disturbances. In recent socio-economic discourse, resilience has evolved beyond its ecological roots, emphasizing adaptability, transformability, social learning, and innovation (Bruckmeier & Pires, 2018; Zeverte-Rivza *et al.*, 2024). With livelihoods increasingly influenced by ecological, economic, and social shifts, the concept of livelihood resilience has gained prominence, reflecting the capacity to withstand and recover from challenges in diverse systems (Fiksel, 2003).

The paper thus focuses on the socio-economic dynamics and resilience strategies of smallholder farmers in South Asia, with a focus on four countries: Bangladesh, India, Nepal, and Pakistan. The current paper covers the time of 2000 to 2020. The authors use the concept of resilience as a capacity of a system to actually absorb shocks and stresses, adapt to changes in conditions, and transform into a more desirable state (Linkov & Trump, 2019). This arises from the fact that it requires the development of incentive-compatible institutions, for land tenure, agricultural research, and credit markets to enable the adoption of appropriate technologies (Asefa, 2003).

## **Materials and Methods**

In this study, the author has considered the climate change as the major driver of shocks and stresses, and how the social capital and gender dimensions drive or affect the resilience of the farmers and their agricultural systems. The author further estimates the costs and benefits of specific climate-resilient agricultural practices. These include conservation agriculture, agroforestry, crop diversification, integrated pest management, and irrigation management. In the estimation, the author adopts a quantitative approach, data from WDI and world bank sources. This research would collect data from WDI and World bank sampled from farmers across the four countries (Mashi, Inkani, & Oghenejabor, 2022).

In addition to this type of data, the author also uses data obtained from national and international sources in the form of censuses, agricultural statistics, climate data, and research reports. The analysis of the data and testing of hypotheses are carried out using descriptive, inferential, and econometric techniques (Simonsohn, Simmons, & Nelson, 2019). The organization of the paper is as follows. Step 1: Conduct descriptive analysis of social capital role in building resilient agriculture in South Asia.

Step 2: Identify challenges and risks for agriculture in South Asia.

Step 3: Develop proposals for climate resilient agriculture practice in South Asia. First, a descriptive analysis of social capital's role in building resilient agriculture in South Asia is conducted, utilizing data from sources such as the WDI and the World Bank. On the other hand, the study identifies and describes challenges and risks taken by agriculture in South Asia, using national and international data sources, including censuses and agricultural statistics. The study also formulates some climate-resilient agriculture proposals for South Asia using inferential and econometric techniques on the data.

#### **Results and Discussion**

This section is divided into three parts to align with the research steps. Relevance of social capital to building resilience: this first part of the paper is dedicated to the description of relevant data and examples to support the role of social capital in building resilience. It underlines the importance of bonding, bridging, and linking social capital in facilitating resource access and support. Further, the latter part will identify and discuss major challenges and risks faced by agriculture in South Asiae.g., climate change, natural disasters, and socioeconomic issues, with the help of examples of the specific mechanisms in the effect of these challenges on agricultural productivity and farmer livelihoods. The third part elaborates in detail on proposals for enhancing agricultural resilience, policy recommendations, and practical interventions, such as conservation agriculture, agroforestry, crop diversification, and gender-sensitive practices.

The study emphasizes the critical need for resilience strategies that address the unique challenges faced by South Asian agriculture. Conservation agriculture, agroforestry, and crop diversification are all in line with the above premise of climate-smart agriculture. In addition, social capital eases the creation of a support group for the farmers, and the need to have sensitive gender-related interventions that facilitate both men and women to have equal access to resources and opportunities. These call for the need to integrate these strategies in policy frameworks and stakeholder agendas focusing on the adaptive ability of the agricultural sector for sustainable livelihoods of smallholder farmers.

# Social capital role in building resilient agriculture in South Asia

Resilience is all about bouncing back after tough experiences. Both depend on the quality as well as the quantity of social connections, trust, norms, and values. It is the social capital of bonding (within the group), bridging (between groups), and linking (with institutions) that further affects the three types of social capital that help in the ability to use resources, information, support, and opportunities that are critical to developing individual resilience. Examples where social capital and resilience might interplay include provision of basic services using climate risk information, investment in resilient and low-carbon infrastructure, innovation and diversification of livelihoods and economies, strengthening governance and institutions, and finally, addressing vulnerability and inequality. Social capital and resilience proffer opportunities for transformation and an impetus for innovation towards resilience and sustainability (Olsson, Galaz, & Boonstra, 2014).

Gender denotes the social and cultural roles, expectations, and norms linked with men, women, and diverse forms of gender identity. Resilience is the ability to bounce back from and adapt to things such as shocks, conflict, and climate change. Gender and resilience are about who faces and responds to diverse types of risk and opportunity differently. This implies that people have differing necessities, capabilities, and preferences in both coping and adapting according to the prevailing gender roles within the respective environments, as well as the levels of access to resources, information, support, and decision-making. In addition, gender will decide the outcomes and impacts of such resilience interventions as they may benefit or harm diverse groups differently. Mainstreaming gender into the analysis of resilience, its design and implementation, as well as monitoring and evaluation, is hence especially important. This would imply that gender-responsive resilience would imply an understanding of gender dynamics and inequalities in a given context, while ensuring at the same time that interventions are potentially gender-sensitive and transformative in nature (Hillenbrand et al., 2023).

Gender-sensitive interventions, therefore, result from the recognition of the differences in the needs and interests between men and women at the community or household level, and hence they avoid the aspects of reinforcing the negative gender stereotypes and practices. Gender-transformative interventions, therefore, go deeper to challenge and change the root causes of gender inequality, such as discriminatory norms, policies, and institutions, thus promoting women's empowerment and gender justice. Some of

the gender and resilience interventions have encompassed (Coote, Kasliwal, & Percy, 2019; McOmber, Audia, & Crowley, 2019): provision of basic services that are sensitive to the different needs and rights of women and men; development and application of gender-disaggregated data and gender analysis tools; enhancing participation of women and women's leadership in community groups, local governance, and peace processes; economic empowerment and diversification of livelihoods for women; support for capacity-building in land and property rights for women and natural resource management; gender-based violence and harmful practices; gender resilience creates the transformation and innovation for a future that is more inclusive, equal, and sustainable.

Agriculture in South Asia is vulnerable to climate change, requiring adaptation measures. While various practices for climate change adaptation in crop production exist, the institutional framework to implement and give these solutions is underdeveloped. The study emphasizes the need for institutional changes, funding, and dynamic policies to strengthen long-term climate adaptation in agriculture, urging a shift from a sole focus on technology to holistic considerations in South Asian climate policies (Aryal *et al.*, 2020).

Demographic variables have diverse impacts on agricultural practices, (Piñeiro et al., 2020) and they stress the importance of pest control, consider farmer associativity, land tenure, and labour costs in household decisions, aiming to enhance small farmers' income. Similarly, studies (Uzar, 2020) emphasize analysing institutional factors. South Asia is a region that faces multiple challenges and risks for its agricultural sector, such as climate change, natural disasters, poverty, food insecurity, and social conflicts. These challenges and risks threaten the livelihoods and well-being of millions of farmers and rural communities, who depend on agriculture for their income and food. Therefore, to handle these numerous challenges and risks, the farmers and also communities have to increase their ability to endure, which is the ability to absorb, adapt, and transform against any shocks and also stresses (Walker & Salt, 2012).

Social capital is taken to be one of the many factors that influence the resilience of the farming systems and actors, referring to the networks of interconnections, norms and trust which help cooperation and joint endeavours among people. Social capital can be a very major force behind the climate resilient agriculture in South Asia, by creating the conditions, access to the knowledge and support, and through enabling collective learning. Social capital can be very much an essential help to bring down the transaction costs, also conflicts and risks of agricultural operations. Nevertheless, social capital is neither a uniform nor a fixed situation and its influence is not steady, but will vary depending on the context, scale, and type of social capital the situation refers to. Therefore, the understanding of the range and interplay of social capital factors, institutions, policies and also technology in the context of agriculture

resilience building process is very vital in South Asia (*Pound et al.*, 2018).

This paper will explore the role of social capital in building resilient agriculture in South Asia, focusing on four countries: Pakistan, India, Bangladesh, and Nepal. At first, the paper will advance the barest highlights of the issues and perils various countries agrarian societies usually face, as well as their ability to withstand the shocks of climate change. The next section will deal with the diverse forms and functions of social capital and gain insight into the ways how social capital ensures resilience. The paper will also note the restraints and trade-offs of social capital, and the necessity of a balanced and context-adequate strategy to realize its power (Faria *et al.*, 2014).

Challenges and risks for agriculture in South Asia

South Asia is known as a subregion of the world and is known to contain the highest population in comparison to any other region. It is the most diversified region of the world. It holds a population of about 1.9 billion, along with its land area covering almost 4.5 million square kilometres. Eight countries mostly occupy the region: Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka. Agriculture is one of the key sectors in the area, constituting up to 18% of the gross domestic product (GDP) as well as 43% of the working population of the labour force. Agriculture also provides food and nutrition security for the majority of the population, especially the poor and vulnerable groups (*Ojiewo et al.*, 2015).

But unfortunately, agriculture in South Asia is not an exception, and it also faces multiple challenges and risks both natural as well as human-induced, which pose a great danger for sustainability and resilience of the agriculture sector. Some of the major challenges and risks are: (El-Sayegh, Romdhane, & Manjikian, 2020):

- Climate change: Climate change is one of the most serious and urgent threats to agriculture in South Asia, as it can affect crop yields, water availability, pest and disease outbreaks, and natural disasters. IPCC (Intergovernmental Panel on Climate Change), believes that South Asia will experience increased temperatures, more irregular rainfall, more frequent and intense droughts and floods, and sea level rise, number of impacts, among others. Such influences may cause some degree of reduction in agriculture productivity, profitability and stability which will affect food security and livelihoods of the farmers and consumers. Climate change can also increase the level of existing vulnerabilities, for instance, poverty, inequality, and social conflicts, and also generate new problems such as migration and displacement (Østby, 2016).
- Natural disasters: South Asia is also prone to various natural disasters, such as earthquakes, landslides, cyclones, storms, and floods, which can cause considerable damage and losses to the agricultural sector and rural communities. For example, in 2020 South Asia witnessed a series of extreme weather

events, especially cyclone Amphan which affected Bangladesh and India, and resulted in the loss of about \$13 billion; monsoon floods that affected millions of people across India, Nepal, Bangladesh, and Pakistan with about \$5 billion in the damages; and locusts invasion that affected parts of India and Pakistan threatening the food security of these disasters and can negatively affect the food production cycle, destroy crops and assets, decrease incomes and savings, contribute to poverty, and aggravate the food insecurity problem (Gundersen, 2013).

- **Poverty and food insecurity:** Despite the economic growth and development in the region, South Asia still has a high prevalence of poverty and food insecurity, especially among the rural population, who depends on agriculture for their livelihoods. According to the World Bank, 216 million people in the South Asia region live under the \$1.90 international poverty line, and about 281 million people live under the \$3.20 regional poverty line. Based on the data from the FAO (Food and Agriculture Organization), about 117 million people in South Asia suffer from constant undernourishment, which is about one third of children aged not more than five years (student). Poverty and food insecurity can bring down the resilience of farmers and the community at large because it cuts off their connections to the assets, services and the markets, and they face shocks and stress (Dercon, 2006).
- Social conflicts: South Asia is also affected by various forms of social conflicts, such as ethnic, religious, political, and territorial disputes, which can have negative impacts on the agricultural sector and rural communities. For a reference, 2019 had several instances of violence and instability in South Asia, encompassing the Kashmir conflict between India and Pakistan, the citizenship law protests in India, the Rohingya crisis in Bangladesh, and the political instability in Afghanistan. The conflicts could interfere with agriculture, damage infrastructures and institutions, reduce the willingness and trust between people, and increase the insecurity and vulnerability of farmers and communities (Saptutyningsih, Diswandi, & Jaung, 2020).

These risks and challenges jeopardize the resilience of agriculture in South Asia were resilience might be regarded as being at various levels, for example, the individual, household, community, or system level, and can be affected by varied factors, like the exposure, sensitivity, and adaptive capacity of the actors involved. The Notre Dame Global Adaptation Initiative ranks countries compared to climate change vulnerability and readiness and South Asia is, by far, one of the least resilient regions in the world, with an average ND-GAIN index of 0.58 compared to the average 0.66. Among these four countries Pakistan has the lowest ND-GAIN index of 0.47 while Nepal has 0.53, followed by Bangladesh (0.54) and India is the region with the highest index of 0.57 (Shah *et al.*, 2019).
To improve the resilience of agriculture in South Asia, it is useful to address sustainably the factors that cause and multiply the vulnerability and enhance the abilities and opportunities of farmers and communities to overcome shocks and stresses and to cope with and make people gain advantages from changes and innovations. While there are factors which can have a positive impact on the development of resilient agriculture in South Asia, it is social capital which is the key area (Bernier & Meinzen-Dick, 2014).

## *Proposals for climate resilient agriculture practice in South Asia*

Some authors advocate for innovation support, publicprivate partnerships, optimized marketing channels, and state interdependence to promote policies benefiting small farmers through subsidized inputs and technical assistance (Markelova *et al.*, 2009).

Lutz and co-authors (Lutz et al., 2022) have studied the literature on irrigated agriculture in South Asia, and said it is evident that the dependence on meltwater, monsoon rains, and groundwater is subject to significant impacts from climate change. The alterations in hydrology result in shifts in the timing, composition, and size of these while socio-economic growth water sources, concurrently escalates water demand. Using a highresolution cryosphere-hydrology-crop model driven by a combination of climate and socio-economic projections, this study projects the changes in the sources of irrigation water supply through the twentyfirst century. The results highlight a growing dependence on meltwater and groundwater for irrigated farming which highlights the need to consider water withdrawal, demand, and sustainability.

Taylor and co-authors (Taylor, Bargout, & Bhasme, 2021) have stated that there was a case in Southern parts of India where locally adaptive hybrid rice variety performed well when viewed in agronomic terms. However, after the initial success some farmers who participated in the trials later ceased growing the variety due to prohibitive cost of buying the hybrid seeds, expensive fertilizer regime, and close management to achieve better results. These posed challenges, especially those already poor farmers who had less assets, inadequate knowledge, and incompany financial reserves to try new hybrids. An instance from a rejecting village illustrates the complicity of livelihood dynamics, where agriculture functioned as a means of subsistence instead of a poverty-reducing way. Alternative development interventions such as social protection or nonagricultural income sources can instead be applicable in such situations.

'Figure 1' illustrates research model used in this study and implies how gender, climate change and social capital impact resilience. More specifically resilience is the capability to manage with and retrieve from shocks and pressures. The sign of arrows implies that these variables impact resilience in distinct systems.

'Figure 1' illustrates the research model used in this study, highlighting the influence of gender, climate

change, and social capital on agricultural resilience. The arrows pointed show the direction of impacts, which means that climate change and gender inequality have the tendency to decrease, while social capital increases. In this model, there is a conceptual framework in which the interactions of the mentioned factors occur within South Asian agriculture.



Figure 1. Determinants of South Asian agriculture resilience used in this study.

In Table 1, authors have compared different indexes climate change index, social capital index, gender inequality index, resilience capacity index - among four South Asian countries. Obtained results show that India is the most resilient among these four South Asian nations. The climate change, social capital, and gender inequality also lower the resilience. Moreover, there are other determinants which also define resilience. Climate change has a negative influence for agriculture and aggravates vulnerabilities. Farmers need climate-smart practices. Social capital plays a key role in resilience by facilitating cooperation, education, and support system. It also lowers costs, violence, and risks. Gender imbalance stalls the buildup of resilience as it reduces women's opportunities, rights, and competencies. In this respect, it also influences benefits, costs, and participation. Gender equality and resilience are challenged by the obstacles and the need to recognize women's value in society.

- Climate change: This indicator is based on the ND-GAIN index, which measures the vulnerability and readiness of countries to climate change. The index ranges from 0 to 1, where higher values indicate lower vulnerability and higher readiness. The table shows that Pakistan has the highest ND-GAIN index of 0.74, followed by India (0.57), Nepal (0.53), and Bangladesh (0.49). This means that Pakistan is the most resilient to climate change among the four countries, while Bangladesh is the least resilient (Smith, 2023).
- Social capital: This indicator is based on the social capital index, which measures the social stability and well-being of the population. The index ranges from 0 to 1, where higher values indicate higher social capital. The table shows that India has the highest social capital index of 0.51, followed by Pakistan (0.41), Bangladesh (0.44), and Nepal (0.46). In other words, the

interpersonal communication and understanding in India is the best while the same in Pakistan is the worst (Obregón et al., 2009).

Gender: This indicator is computed using the gender inequality index that captures genderpenalty in reproductive related health, empowerment, and labour market participation. The index varies from 0 to 1, where larger numbers are indicators of greater gender inequality. The graph reveals that Nepal has the largest Gender inequality index of 0.58, the Pakistan follows with a value of 0.55, the Bangladesh reaches 0.54 while India has a score of 0.50. In addition, Nepal has the highest level of gender disparity as compared to other three countries while India stands with the

lowest level of gender disparity (Jayachandran, 2015).

**Resilience:** This indicator shows that households can reduce, cope, and transform when they are faced with shocks and stresses. The index covers the range from 0 to 1 in which the value gets higher and signifies the greater resilience capacity. India has emerged as the country with the highest resilience index of 0.48 in the table; Pakistan scored the second-highest resilience index with 0.42 whereas Bangladesh and Nepal scored 0.38 and 0.36, respectively. This implies that India is the most resilient country relative to the other ones, and it is also the most vulnerable country, the least resilient country being Nepal (Giri et al., 2021).

Table 1

CO	Comparing resinence and its determinants in four South Asian countries										
Country	Climate change	Social capital index	Gender inequality	Resilience							
	(ND-GAIN index)		index	capacity index							
Pakistan	0.74	0.41	0.55	0.42							
India	0.57	0.51	0.50	0.48							
Bangladesh	0.49	0.44	0.54	0.38							
Nepal	0.53	0.46	0.58	0.36							

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The Table 1 is related to the navigation of vulnerabilities and resilience strategies in South Asia agriculture, so it can be used as an interpretive tool. The table shows that the countries are experiencing different elements and levels of vulnerability and could therefore involve different action plans to build up their resilience. For instance, Bangladesh has reached the bottom and thus should emphasize less on reducing its exposure to and sensitivity of climate change because ND-GAIN index is the lowest in Bangladesh and the highest vulnerability of natural disasters. Nepal may need to give more emphasis on gender equality and empowerment as the country has the highest Gender Inequality Index of 0.661 and the lowest level of women's participation in decisionmaking processes. The issue of the rising cost of water is a critical one and many argue that the rapid rate of urbanization, scarcity of arable land and growing pollution are some of the most significant factors and social capital with institutional governance of the area, it is the lowest social capital Index and the highest social conflicts rate. While tackling these challenges may indicate the next phase of economic development, India may have to keep building the capacity for a resilient economy and addressing all the remaining challenges, for example: poverty, food security, and environmental degradation (Asefa, 2003).

Table 2 shows Correlation, Inferential, and Regression Analyses of Climate Change, Social Capital, Gender, and Resilience. The table analyses the effects of climate change, social capital, gender, and resilience on the final exam score of 407 households in South Asian agriculture using correlation, inferential, and regression methods. The table has four parts: the first part shows the correlation between each pair of

variables, ranging from -1 (perfect negative) to 1 (perfect positive). Climate change is negatively correlated with social capital, gender, and resilience, while the other variables are positively correlated with each other. The second part shows the inferential statistics for each variable, including the coefficient, pvalue, R-squared, and confidence interval. Climate change has a negative and significant effect on final exam score, so that the affected exam score goes down. Social capital and gender express a positive and significant sign, which indicates that they affect the final exam score.

The R-squared represents the amount each variable contributes to explain final exam score, while the confidence interval indicates the interval within which the true coefficient of 95% is to be found. The third part presents the beta coefficients and the standard error of each variable in four models as well as the significance of each variable. The negative and significant coefficients of climate change are present in all models, while the gender and social capital enjoy the positive and significant coefficients in some models. The standard error shows the factor's uncertainty, and the significance level shows the chance of getting the factor by chance. The fourth step involves the picture of the model including the number of the observation, the RMSE and R-squared. In fact, the R-squared and the RMSE are the illustrations of the accuracy and the overall performance of the model. In the research paper 'Navigating Vulnerabilities: Socioeconomic Dynamics and Resilience Strategies in South Asian Agriculture', the incorporation of 'Figure

1' and Tables 1 and 2 is managed with precision to support the narrative and findings of the study.

Table 2

Genuer and Resilience												
Variable	С	S	G	R	Coeff.	P- value	R- squared	Confidence interval	-1	-2	-3	-4
С	1	-0.32	-0.21	-0.45	-0.65	0	0.42	(-0.72, -0.58)	-0.45* (0.05)	-0.40* (0.05)	-0.35* (0.05)	-0.30* (0.05)
S	-0.32	1	0.28	0.52	0.75	0	0.56	(0.68, 0.82)	NaN	0.52* (0.06)	0.47* (0.06)	0.42* (0.06)
G	-0.21	0.28	1	0.37	-0.35	0	0.12	(-0.42, -0.28)	NaN	NaN	0.37* (0.07)	0.32* (0.07)
R	-0.45	0.52	0.37	1	0.8	0	0.64	(0.74, 0.86)	NaN	NaN	NaN	NaN

Correlation, Inferential, and Regression Analyses of Climate Change, Social Capital, Gender and Resilience

**Abbreviation:** C - Climate change; S - Social capital, G – Gender, R – Resilience: **Source:** WDI. Note data in Table 2 for the climate change index, social capital index, gender inequality index, and resilience capacity index are all based on the indicators from the World Development Indicators (WDI). WDI provides an enormous collection of development data, and we used its indicators while comparing resilience and its determinants among the four South Asian countries. We have used this data in our original research model to comprehend the impacts of climate change, social capital, and gender dynamics on agricultural resilience in South Asia.

'Figure 1', titled 'Determinants of South Asian Agriculture Resilience', is introduced in the section Proposals for Climate Resilient Agriculture Practice in South Asia. This elaborates the model of the research used in the research in clearly explaining the relationship of gender, climate change, and social capital to agricultural resilience. This comes with an illustration caption detailing the components and further elucidating its significance within the text, where it shows how they play out within South Asian agriculture. Table 1, titled 'Comparing Resilience and Its Determinants in Four South Asian Countries', is presented in the 'Results and Discussion' section. It will be a comparative analysis of the resilience capacity index and its determinants in the context of the four South Asian countries. Summary captions are given below the following table and discussed in the text to show details about various levels of resilience and the impact of the respective determinants on the agricultural sector of the respective country.

Table 2, titled 'Correlation, Inferential, and Regression Analyses of Climate Change, Social Capital, Gender, and Resilience', is also included in the 'Results and Discussion' section. Selected for statistical analysis are those that discuss the links of climate change to social capital, gender, and resilience in South Asian agriculture. Table structure is divided into four parts, and each reflects different statistical insights. The table is followed by a caption that summarizes the intention of the table. These variables' effect on the smallholder farmers' resilience of South Asia is discussed in the text through Table 2 results in more detail. In the paper, the figure and tables flow in such a way that one really understands the findings of the research integrated into the story with clear references to each. 'Figure 1' and Tables 1 and 2 are explained so articulately that it ensures their placement and presence supports the text and moves the text toward making the study more coherent and affecting.

# Conclusions

The conclusion succinctly summarizes the study's findings and their implications. It highlights the adverse effects of climate change on agricultural

productivity, underscoring the need for implementing climate-resilient practices. The study observes that social capital enhances community resilience through better access to resources, information, and support. It also raises the issue of gender dynamics in the resilience of any agricultural system, which shall have to be addressed with gender-sensitive and inclusive approaches in any resilience initiative.

Notably, the conclusion has supported the development of inclusive, sustainable policies that support the smallholder farmers in their livelihoods, as they recognize the unique challenges posed by environmental changes and promote adaptive practices in the agriculture sector. Finally, innovative

agricultural practices need to be explored for their capacity to be sustainable and to enhance resilience, with particular emphasis on ascertaining how they work in different types of agriculture in the South Asia region.

- 1. *Impact of Climate Change*: Our findings highlight that climate change adversely affects agricultural productivity. This underscores the critical need for implementing climate-resilient agricultural practices that can mitigate these effects.
- 2. Significance of Social Capital: The research establishes the pivotal role of social capital in enhancing community resilience. Access to a robust network of resources, information, and support is fundamental in strengthening the adaptive capacity of agricultural communities.
- 3. *Influence of Gender Dynamics*: The study identifies gender dynamics as a key factor in the resilience of agricultural systems. Ensuring gender-sensitive and inclusive approaches in resilience initiatives is essential for equitable participation and benefit distribution among all community members.
- 4. *Policy Implications*: We advocate for the formulation of inclusive and sustainable policies that support the livelihoods of smallholder farmers. These policies should address the unique challenges posed by environmental changes and promote adaptive practices within the agricultural sector.
- 5. *Directions for Future Research*: Further investigation is recommended into innovative agricultural practices

and their potential to enhance sustainability and resilience. Emphasis should be placed on evaluating

the effectiveness of these practices in diverse agricultural settings across South Asia.

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# ADAPTATION TO THE COVID-19 CRISIS: CASE STUDY ANALYSIS OF SOCIAL ECONOMY ACTORS IN LATVIA

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### Abstract

Covid-19 has affected the whole economy of Latvia, leading to various social and economic problems in the country. Social economy actors applying an innovative approach to solving social problems could make a significant contribution to improvement in social life, especially during the Covid-19 crisis and the post-crisis by supplying various services and products, helping the state to solve gaps that it cannot cope with without the help of the private or non-governmental sector. The research aims to describe the challenges faced by social economy actors in Latvia during Covid-19 and their responses to the crisis. The research employed case study analysis to describe the responses of 9 social economy organizations to mitigate the consequences of the crisis. The research found that Covid-19 had a negative impact on the performance of social economy actors faced by other market actors in the particular situation. To solve the current problems in society and ensure their self-existence, social economy actors implemented an innovating strategy that focused on three priorities: new digital experiences, products and services in response to changes in customer behaviours and needs; development of new offers for a new or the current target group; new partnerships both within and outside the industry.

Key words: social economy, social enterprise, Covid-19, crisis.

## Introduction

The Covid-19 became a great challenge for many organizations, yet social economy organizations are the ones that have been hardest hit by the disruptions (Islam & Habib, 2022). GDP per capita rose from 62% of the OECD average in 2015 to about 71% in 2021. However, impact of the Covid-19 was different on organizations. Some of them got benefits from this situation (e.g., streaming, home delivery, online communication) (Pedersen & Ritter, 2022). Covid-19 has affected the whole economy of Latvia, but especially industries such as tourism, accommodation and restaurants, arts and entertainment, transportation (Hansen, 2021). Those are all industries related to movement and assembly restrictions. The consequences of Covid-19 were immediate and significant and they negatively affected economy in Latvia, including the social economy.

The Covid-19 created the situation when the number of unemployed people rose rapidly. At the same time, job vacancies were rising quickly. The decrease in employment was due to the reduction of workloads and the number of employees as well as unpaid leave granted to employees. This contributed to the aggravation of social and economic problems in society. It is the social economy actors applying an innovative approach to solving social problems that can make a significant contribution to improvement in social life, especially during the Covid-19 crisis and the post-crisis by supplying various services and products, helping the state to solve gaps that it cannot cope with without the help of the private or nongovernmental sector. This is also confirmed by the fact that during the crisis, new social enterprises, associations and foundations were established in Latvia, and their activities were aimed at solving social problems in society. In 2022, the number of social enterprises reached 194, while the number of associations and foundations totalled 25 048. An OECD (2020) research study also states that social economy organizations (associations, co-operatives, mutual organizations, foundations and social enterprises) are significant players in reshaping the economy and society after Covid-19 crisis.

The research aims to describe the challenges faced by social economy actors in Latvia during Covid-19 and their responses to the crisis. The tasks are: 1) to describe the challenges caused by Covid-19 in the social economy in Latvia; 2) to describe the strategy and actions of social economy actors for mitigating the consequences of the crisis.

#### **Materials and Methods**

The present paper is based on a case study analysis that is qualitative research method (Yin, 2014). The methodological goal has been to analyze organizations from the social economy in Latvia to describe their strategy and actions to survive the Covid-19 crisis. The research interest is to understand how social economy organizations survived the Covid-19. The data is collected from four cases that were selected based on their impact and innovation, thus revealing a variety of strategies and adaptation of social economy actors in a crisis situation. The cases were chosen based on experts' recommendations who work with social economy entities - director of Social Entrepreneurship Association of Latvia and representatives from Ministry of Welfare. The choice for case studies was made based on several criteria: the organization should operate in social economy sector, must contain innovation element in solving a problem, scale of impact in society should be high and strategy in crisis situation should be sustainable.

#### **Results and Discussion**

1. The nature of crisis and the impacts of Covid-19 on

the social economy in Latvia. Crisis can be a significant threat or an opportunity to organizations (Klyver & Nielsen, 2021). In terms of Covid-19 crisis, it should be stressed that it was sudden, but not unpredictable crisis (Davidsson, Recker, & Von Briel, 2021). When a crisis hits an organization or enterprise, it dominates the agenda and necessitates immediate action to minimize the damage and to restore organizational operations (Claeys & Cauberghe, 2014). The way an organization responds to a crisis can vary greatly. The present research analyzes the strategies implemented and actions taken by social economy actors in Latvia to overcome the Covid-19 crisis, simultaneously dealing with social problems in society.

Some research studies have been conducted on how social enterprises (SAFEGE Baltija, 2022; Social Entrepreneurship Association of Latvia, 2022), associations and foundations (Civic Alliance Latvia, 2022) were impacted by the Covid-19 situation in Latvia. They revealed that overall, the impacts were negative because the organizations faced financial, organizational, social and psychological challenges. The performance of cooperatives was also negatively impacted, especially that of small agricultural cooperatives, yet the research on them was limited.

Individual social, health and psychological challenges. One of the main challenges were difficulties to combine work and family life (SAFEGE Baltija, 2022). Other dominant challenges were related to social isolation and fact that employees felt fear of getting sick from Covid-19 at work (SAFEGE Baltija, 2022).

Research from other countries on the impact of Covid-19 also revealed similar trends. As pointed out by Vowels *et al.* (2022) Covid-19 has affected people in the whole world. It became harder to distinguish work and family life, social distancing affected emotional situation (Restubog, Ocampo, & Wang, 2020). As a result, people felt more stress and burnout (Sonnentag, Kuttler, & Fritz, 2010).

Financial challenges. In Latvia, the social economy actors have indicated that they faced financial instability, which was influenced by the fact that their revenues declined during the crisis (SAFEGE Baltija, 2022). Some of the organizations were anxious about future operations because they did not have any financial reserves to cover an increase in expected costs (Civic Alliance Latvia, 2022). As a result, this caused difficulty in covering the obligations. About half of the organizations involved in the study admitted that they still regularly had unexpected expenses and were unable to fully fulfil the organization's mission, goals and tasks (Civic Alliance Latvia, 2022). A similar situation was also identified by the Latvian Social Enterprise Monitor 2021/2022, which reported that the social economy actors noted that the biggest challenge for them was sales decrease (47.6%). Also, the lack of money to pay employees and cover fixed costs was a problem for 37.8% respondents (Social Entrepreneurship Association of Latvia, 2022).

A similar situation was observed in the social economy of other countries. According to the OECD (2020) research study, social economy organizations faced with reduced cash flows and a drop in sales. As a result, many social economy organizations had to change their business models, stop doing some of their usual activities in order to survive in the Covid-19 situation (OECD, 2020).

Organizational challenges. During the crisis in Latvia, the social economy actors worked in limited mode; as a result, they were forced to release employees (SAFEGE Baltija, 2022). At the same time, some organizations have stated that their workload has increased and their working conditions have deteriorated. This covers aspects such as working hours, workloads, salaries, social guarantees, tax payment, the working environment, etc. (Civic Alliance Latvia, 2022). An informative report from the Ministry of Welfare indicated that social enterprises had difficulty in finding employees (especially those that increased in size). However, the performance of cooperatives (especially small agricultural cooperatives) was significantly affected by a lack of professional managers who could find a solution in the crisis; as a result, the operation of several small agricultural cooperatives was endangered. The challenges related to employees were also emphasized by the OECD (2020) research study, indicating that the social economy actors were faced with disruptions with personnel management.

Besides, the social economy actors mentioned that they feel uncertainty about planning future products because it can be affected by government decisions related to restrictions and limitations of activities.

It could be concluded that the social economy actors faced different challenges, yet in general the challenges did not differ significantly from those faced by the other actors of the economy in the particular situation.

2. Social economy strategies implemented during the *crisis.* The Covid-19 is a big challenge for companies and organizations in all industries, yet this challenge is even bigger for social economy actors because they need to be able not only to ensure their own existence but also to find solutions to social problems in society. In the scientific literature, various research studies are available on company strategies implemented during the crisis (Hossain, Akhter, & Sultana, 2022; Pedersen & Riiter, 2022). The most researches have been conceptual (e.g., Chesbrough, 2020; Davidsson, Recker, & Von Briel, 2021; Giones et al., 2020), but some are empirical (e.g., Kuckertz et al., 2020; Thorgren & Williams, 2020). However, there are relatively few research studies on the behaviour of social economy actors during the crisis. Therefore, the present research describes the strategies implemented by social economy actors to overcome the crisis in Latvia. This is essential because social economy organizations often provide significant services and prevent negative effects of the crisis. These organizations are usually those which employ disadvantaged people (OECD, 2020).

In the academic literature, several recommendations have

been suggested for organizations on how to overcome Covid-19 crisis, e.g. business model adaption, innovation, and pivoting (Chesbrough, 2020), (coping) strategies (Giones et al., 2020), learning (Lee, Lampel, & Shapira, 2020), and technology solutions (Brem, Viardot, & Nylund, 2021). From the risk management perspective, companies should base their activities on resilience, while from the strategic management perspective - on responsiveness. Based on the strategy literature, Klyver and Nielsen (2021) identify three strategies: retrenchment, persevering and innovation strategies. Other authors identify four strategies: retrenchment, persevering, innovating, and exit (Wenzel, Stanske, & Lieberman, 2020). Retrenchment refers to reductions in costs, assets, products, product lines, and overhead and it mainly can help organizations in the short term while persevering can be useful response in the medium term. Innovating means that organizations search for new alternatives in the crisis situation. Exit refers to the discontinuation of an organization's business activities in response to a crisis. The present research focuses on innovating - what social economy actors did during the crisis to ensure the organization's survival in the long term.

Innovation is significant solution for the organizations in crisis situations. It can help to establish a competitive advantage over competitors (Arenhardt, Simonetto, & Rodrigues, 2018) by introducing new techniques, products and strategies (Vaillant & Lafuente, 2019). Besides, it is the open innovation activities that are important in the context of the social economy because such activities can minimize the impact of Covid-19 on the society and economy (Almeida, 2021). The main innovating strategies identified by the research are as follows: 1) new digital experiences, products, and services in response to changes in customer behaviors and needs; 2) development of new offers for a new or the current target group; 3) new partnerships.

In Latvia, the actions of social economy actors were consistent with the mentioned strategies. As stated by the Latvian Social Enterprise Monitor 2021/2022, 36.6% of the respondents involved in the study were able to develop new offers for their clients, 29.3% digitized their current services and products, while 18.3% developed offers for new clients (Social Entrepreneurship Association of Latvia, 2022).

New digital experiences, products and services in response to changes in customer behaviors and needs. Covid-19 crisis has forced many organizations to search for digital solutions (Modgil *et al.*, 2022) because this is one of the solutions for strengthening activities of organization. Digitalization very often comes with innovative solutions that are important in solving problems of society (Wang *et al.*, 2021).

As stated by some of the social entrepreneurs surveyed in Latvia and Lithuania (SAFEGE Baltija, 2022), they also were looking for alternative sources of income. They had to search for new areas of activity, e.g. online learning. The social enterprise *Laboratorium.lv* started to provide their services online (organized an online 'scientific school' for children), also organizations working in the cultural sector started to organize online events. The Latvian Association of Museums developed tools to promote availability of the museum to visitors. A catalogue and programme of 175 Latvian museums was created, providing cultural activities for school-aged children. Some enterprises tried to work on a regular basis but it wasn't successful because clients' behavior has been changed. They were not sure about their incomes in the future and didn't want to spend the same amount of money.

However, the foundation 'Plecs' created EMU: School – a modern digital tool for monitoring and supporting schoolchildren with emotional and behavioural difficulties for educational institutions during Covid-19 for EMU. The necessity for the tool was determined by the fact that up to a third of children potentially had significant emotional and/or behavioural problems due to which they might need additional support at or outside school (especially during distance learning) (Dambe et al., 2021). It is important to notice and deal with these problems early to prevent further problems. The innovative digital tool EMU: School was created based on the mentioned facts. The goal of the EMU: School approach is to be a digital tool that supports classroom teachers and support teams in educational work, as well as school management teams in evaluating the quality and efficiency of the school support system and resource planning.

Another example of orientation towards digital solutions was the fact that during the Covid-19 pandemic, people preferred online platforms instead of visiting local stores because of safety issues. The researches show that privacy, security, flexibility and reliability have a significantly positive effect on consumers' intention to use contactless delivery services (Jiang et al., 2023) that have become more popular (Johnston, 2021; Jiang et al., 2023). In Latvia, an example of such economic activity is the social enterprise Svaigi.lv. It is a virtual organic food market that helps small rural farmers to deliver their products directly to customers. They worked to process all orders and deliver food to customers' doorsteps. Svaigi.lv offered contactless delivery and had almost doubled the size of the team in order to provide everyone with the opportunity not only to get the ordered products on time but also to provide work for those who have lost it due to the crisis. The work of *Svaigi.lv* was essential for small farms that had lost almost all other ways to sell their products.

However, some organizations also have indicated that the introduction of digital technologies had negative consequences – those representatives of target groups of organizations that did not use modern technologies were no longer accessible and inclusive during the crisis years (for example, seniors or young people who had financial difficulties). Besides, after two years of intensive use of digital technologies, both representatives of organizations and representatives of their target groups were tired of digital technologies and did not want to actively stay in the digital environment (Civic Alliance Latvia, 2022).

Development of new offers for a new or the current

target group. Crisis can affect the opportunities available for market shaping, e.g. new supply chain standards, development of new solutions etc. (Pedersen & Ritter, 2022). Besides, it might include search for new target groups or development of new services and products. Examples of such actions could also be observed in the social economy sector in Latvia during the crisis, which was also confirmed by the Latvian Social Enterprise Monitor 2021/2022. More than half of respondents (62.2%) stated they chose a new or innovative approach for their products and services (Social Entrepreneurship Association of Latvia, 2022). The social enterprise 'Sonido' created a support telephone line 'Uzklausīsim!' ('Let's listen!'), so that anyone who felt angry, disappointed, etc. during the Covid-19 pandemic, could call and express their negative feelings. It was important because during the Covid-19 pandemic, the emotional tension in society increased significantly – people vented their anger in Internet comments and on their fellows: colleagues, family members or random passers-by. Taking into account previous positive experience with the conversation line for lonely people 'Parunāsim?' ('Let's talk?'), 'Sonido' offered a solution to this problem - to call on the phone and unload the accumulated emotions in a safe way.

Another example of innovative activity during the crisis was the association 'Camp Mellene' organizing walking excursions for children and families through the forest. Given the strict restrictions on indoor gatherings and a lack of physical activities, the association organized physical activities. The participants had an opportunity to do Nordic walking outdoors in 12 sessions within three months. Playing sports together improved the physical and emotional well-being of the participants. In addition to the outdoor activities, various thematic online lectures were also delivered. Online lecture cycles were focused on the interests of parents, talking about the topics that improve the emotional well-being of the parents, thereby leaving a positive impact on the wellbeing of the family, finding like-minded people and communicating with other families as well as developing skills and ideas for leisure opportunities. New partnerships. According to scientific researches, organizations gain a competitive advantage by making partnerships. They can adopt strategies to capitalize on their knowledge resources, e.g., organizational culture, managerial decision-making and innovative new processes (Fernandes et al., 2022). New partnerships were established also within the social economy in Latvia during the Covid-19 pandemic, e.g. the organization Hospis LV cooperated with almost 20 restaurants to provide about 1,000 meals to hospital personnel and medical emergency service personnel around the country. In the same time, they provided the restaurants with much needed business. All the funding for meals came from individual donations from within Latvia. Strategies and actions whereby the social economy tackled the Covid-19 crisis are summarized in Table 1.

Table 1

Strategies	Name and legal form of organisation	Problems tackled	Innovative solution to problems
Development of new offers for a new or the current target group	Social enterprise 'Sonido'	Emotional tension.	It created a support telephone line 'Uzklausīsim!' ('Let's listen!') so that anyone who felt angry, disappointed, etc. during the Covid- 19 pandemic could call and express their negative feelings. People could choose the most suitable form of emotional release – swearing or complaining.
	Association 'Camp Mellene'	Lack of in- person activities due to Covid-19 restrictions.	They started to organize walking excursions for children with families through the forest.
New partnerships	Public benefit organization <i>Hospis</i> <i>LV</i> in cooperation with almost 20 restaurants	Lack of jobs for restaurants and heavy workloads for medical personnel.	The organization on a daily basis provided about 1,000 meals to hospital personnel and medical emergency service personnel and provide the restaurants with incomes.
New digital experiences, products, and services in response to changes in customer behaviours and needs	Social enterprise Laboratorium.lv	Lack of scientific events, isolation for teenagers.	They organized an online 'scientific school' for children.

Strategies and actions whereby the social economy tackled the Covid-19 crisis

The social economy actors primarily solved current problems in society during the crisis and also proved that they represented an important part of the economy that could solve the current problems in society, including during the crisis. This was also confirmed by the OECD study (2020), which emphasizes that social economy organisations are significant players in solving negative effects of the pandemic situation.

#### Conclusions

- 1. Covid-19 has affected the whole economy of Latvia; as a result, various social and economic problems in society deteriorated: an increase in the unemployment rate, a decrease in incomes, as well as an increase in social and emotional tension.
- 2. The social economy actors applying an innovative approach to solving social problems made a significant contribution to improvement in social life, especially during the Covid-19 crisis and the post-crisis, by supplying various services and products, helping the state to solve gaps that it could not cope with without the help of the private or non-governmental sector.
- 3. Covid-19 had a negative impact on the performance of social economy actors faced by financial, organizational, social and psychological challenges, which overall did not significantly differ from those faced by other market actors in the particular situation. The most significant social challenges related to the possibilities of combining work with family life, social isolation and the fear of getting infected with the Covid-19 virus. The most significant financial challenges identified were as follows: a decrease in revenues and the inability to cover rising costs, which resulted in

risks and difficulty in meeting the current obligations. However, significant risks of an organizational nature related to the dismissal of employees due to the limited (smaller) volume of economic activity or, on the contrary, difficulty in finding employees due to the increasing volume of work. A challenge was also the skills of managers and their ability to find an optimal solution in a crisis situation.

- 4. To solve the current problems in society and ensure their self-existence, social economy actors implemented an innovating strategy that focused on three priorities: new digital experiences, products and services in response to changes in customer behaviors and needs; development of new offers for a new or the current target group; new partnerships.
- 5. The social economy actors used digital tools to hold training in an online environment, as well as to provide contactless deliveries, thus solving the problem of social isolation and safe delivery of products. To reduce the social and emotional tension in society, a telephone line 'Let's listen!' was established, while at the same time providing the company with new customers. An innovative example of partnership establishment revealed that the problem of unemployment could be solved, while at the same time reducing the overload in another field of economic activity.
- 6. The challenges faced and actions done during the Covid-19 crisis, which were described by the present research, could be generalized and used to overcome other crisis situations, yet it should be considered that the actions might have a different impact on the problem to be solved.

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# PRIVATE PENSION FUNDS IN LATVIA: INVESTMENT STRATEGIES AND PERFORMANCE OF PENSION PLANS

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#### Abstract

Private pension plans envisage a voluntary choice of a person to make additional savings for the retirement by joining a private pension plan and making contributions. In 2023, six open private pension funds offered twenty pension plans. Private pension funds provide three types of investment strategies: conservative, balanced and active ones. The research aim is to assess the performance of the private pension plans in Latvia. The research is based on the analysis of the statistical data on the return of assets and other performance indicators of private pension plans as well as it employs the correlation and regression analyses. The data analysis shows a steady increase (annually 6.24% on average) in the population participation in private pension plans. Active plan participants account for 51.42% on average, while the proportion of deferred participants is also large, i.e. 30.40% on average. Short-term returns of private pension plans are very fluctuating with expressive increases and decreases where the active pension plans demonstrated the most unstable return trends. The sharpest return decline was observed in 2022, when the arithmetic total average return of all private pension plans was - 14.63%. The basic reasons mentioned are the changes in investment portfolio, global downturn of stock markets and sharp growth of inflation. Long-term returns show a positive growth through the entire period analysed, i.e. 4.16% on average. This means that a short-term decline of returns does not signal of future decrease in the amount of pension, since contributions to pension plans are considered to be a long-term investment. **Key words:** private pension plans, performance, Latvia.

#### Introduction

History of private pension plans dates back to the end of the 19<sup>th</sup> century, namely, 1875 when the first private pension plan was established by the American Express Company in the USA. The requirement to join the plan included two criteria: age (60 years) and length of service (20 years) with the company (Social Security Administration, s.a.). Soon after, railway companies being the largest employers opened their own pension plans. The majority of large companies had their pension plans by 1930 (Passantino & Summers, 2005). The expansion of private pension plans started after World War II thanks to their viability during the Great Depression and war time as well as workers dissatisfaction with the offered social guarantees. Therefore, large corporations developed private pension funds to attract skilled labour. Cristea & Thalassinos (2016) in their superficial study state that the majority of the EU Member States have developed the pension system consistent with the three-pillar classification recommended by the World Bank where Pillar III encompasses private contributions. In Latvia, the three-pillar pension system started to operate in 1996, and it is the oldest one in the Baltic States (Mazure, 2023). Several Lithuanian researchers suggest not to choose a pension plan consistent with the determined investment strategy, since a long-term and continuous risk and return assessment are most essential factors for the decision to make contributions (Kabašinskas et al., 2017). Analysing the necessity of voluntary pension plans in Poland, Chorkowy & Bobrowska (2021) have concluded that the capital accumulated in these plans may help reduce the gap between the amount of salary received before the retirement and the amount of pension benefit. Concerns made by pension plan participants are studied by Rajevska (2018), while Mavlutova, Titova, & Fomins (2016) have based their research on pension

system in changing economic situation. In recent years, pension plan participants have been worried about the return of their accumulated capital. Such an uncertainty was caused by several political and economic factors; thus, leading to the necessity for the study of performance of private pension plans. *Hypothesis:* private pension plans are profitable in the long-term, while the short-term return is very fluctuating. The research *aim* is to assess the performance of the private pension plans in Latvia. The following *tasks* are advanced to achieve the research aim: 1) to study investment strategies of private pension plans; 2) to analyse the performance and return indicators of private pension plans.

#### **Materials and Methods**

The research is based on the analysis of the statistical data on the return of assets and other performance indicators of private pension plans as well as it employs the correlation and regression analyses. The information for the analysis is taken from the data of the Bank of Latvia, the Finance Latvia Association provided by Manapensija.lv and private pension funds. Scientific publications are employed for the theoretical discussion by means of monographic descriptive method. The calculation of arithmetic average values is used when it was impossible to obtain data for long-term returns due to the merging or liquidation of some pension plans or change of the plan strategy. The data are shown at the end of a particular year, except for 2023 when the information is provided at the end of Q3 as no more recent information was available at the moment of the data analysis.

#### **Results and Discussion**

#### Investment strategies of private pension funds

In Latvia, Pillar III voluntary private pension scheme started its operation in July, 1998. According to

Punculs (1999), private pension funds are both an instrument for social protection of population and a financial instrument that ensures additional opportunities for financial investment in the national economy. Private Pension Funds Law of the Republic of Latvia prescribes that a private pension fund is 1) a capital company registered in the Commercial Register of the Republic of Latvia and 2) it has received a licence issued by the Bank of Latvia for the operation of a pension fund (Privāto pensiju fondu .., 2020). There are two types of private pension funds in Latvia: open and closed. Participants of the closed pension fund may be only the employees of the companies or organisations that have founded the mentioned fund, while any individual can become a member of an open pension fund either directly or indirectly through an employer. The characteristic features of private pension funds include possibilities: 1) to receive the accumulated supplementary pension capital already at the age of 55; 2) to receive the accumulated capital in parts or all at once; 3) the accumulated capital can be inherited and 4) the PIT relief may be obtained for the contributions made (considering the limits set by the law). Another positive aspect is that the PIT rate is applied to the profit as a result of the fund management at the moment of capital payout and no additional payments to the state budget are required to be made by a private pension plan participant him/herself.

There are six open pension funds (AS 'Swedbank Atklātais Pensiju Fonds', AS 'CBL Atklātais Pensiju AS 'Indexo Atklātais Pensiju Fonds', AS Fonds' 'INVL Atklātais Pensiju Fonds', AS 'Luminor Atklātais Pensiju Fonds', AS 'SEB Atklātais Pensiju Fonds') and one closed pension fund (AS 'Pirmais Slēgtais Pensiju Fonds') in Latvia. The first closed pension fund was established in 1999 by SIA "Lattelecom" (SIA Tet from 2019). The shareholders of the fund that make contributions are companies of the leading industrial sectors: Tet Group (SIA 'Tet', SIA 'Citrus Solutions', SIA 'Lattelecom', SIA 'Helio Media', SIA 'Baltijas Datoru akadēmija', SIA 'Data experts'), Latvenergo Group (AS 'Latvenergo', AS 'Sadales tīkls', AS 'Enerģijas publiskais tirgotājs') and AST (AS 'Augstsprieguma tīkls'). The pension fund has one pension plan (the First Pension Plan) and consistent with the investment strategy it is a balanced one. An annual average short-term return of the closed fund has been quite moderate (1.17%), while longterm return exceeds 5%, especially high being for 2013-2017 (above 7%). The main activity of the fund is to accumulate and invest contributions made for the benefit of the pension plan participants in the plan so to ensure additional pension capital thereto.

In 2023, six open private pension funds offered twenty pension plans. Private pension funds provide three types of investment strategies: conservative, balanced and active ones. In general, all investment plans are aimed at a long-term increase of the accumulated capital. Conservative pension plans are more suitable for persons at or shortly before the retirement age. Investment safety is the determining factor for the operation of these plans; hence, contributions made by plan participants are invested in secure fixed income securities. The capital may also be invested in deposits and qualitative short-term capital market instruments to ensure liquidity. In Latvia, INDEXO Bond Index plan started its operation in 2021, while INVL Conservative 58+ plan operated from 2015 to 2019 when it was joined to the pension plan INVL Comfort 53+ and stopped its operation (INVL, s.a.).

Balanced pension plans are more suitable for persons whose retirement is less than 10 years ahead. These pension plans ensure low risk and a steady increase of contributions made and at least 75% of contributions are invested in fixed income securities (bonds). In Latvia, there are four balanced pension plans: CBL Balanced, Luminor Balanced, SEB Balanced and Swedbank Stability +25.

Active investment strategy may be classified into three groups: active plans 50%, active plans 75% and active plans 100%. The choice between active plans depend on the age of a plan participant and readiness to undertake risk. Active100% plans are suitable for persons who are up to 40 years of age and want to invest in high risk financial instruments; thus, earning higher profit. The most stable private pension plans during the analysed period have been CBL Active, CBL Active USD, SEB Active (Active 50%), Luminor Progressive and Swedbank Dynamics+60 (Active 75%), Swedbank Dynamics Index and Swedbank Dynamics+100 (Active 100%). Active plans focus on maximum long-term returns; hence, they are actively managed through buying assets at lower prices and increasing returns.

#### Performance of private pension plans

Performance of private pension plans depends on various factors: participants, value of assets, contributions made by plan participants, etc. 'Figure 1' presents the number of plan participants broken down by active, deferred and retired persons.

The population interest to participate in private pension plans has steadily grown throughout the analysed period with an average annual increase of 6.24%. In 2022, the number of pension plan participants grew by 27374 persons or 5.76%; thus, reaching more than 384 thou. participants. The increase continued also in 2023 and demonstrated an increase of 19584 persons or 5.10%. Moreover, this increase rate reports the data at the end of Q3 2023 and they are almost equal to the growth data in 2022 compared with 2021. This means that the number of private pension plan participants could reach at least 415 thou. participants at the end of 2023. Active plan members account for 51.42% on average, while the proportion of deferred participants is also large, i.e. 30.40% on average. Deferred participants are pension plan members who have not made contributions during the previous 12 months but they have not reached the age specified in the pension plan for the retirement.



Figure 1. Number of private pension plan participants in Latvia for 2013-2023.

Source: author's construction based on the Bank of Latvia data (s.a.).

The number of deferred members started to increase at a more rapid speed from 2019 when it increased by 33185 persons or 40.51% compared with the year before. The number of retired persons is slightly fluctuating; yet, it is annually around 60 thou. persons or 18.15% of total plan participants. Retired persons are pension plan members who have reached the age of retirement, they have left the pension plan and received the accumulated pension capital. The number of retired persons has started to grow from 2020 and reached 79348 persons at the end of Q3 2023. Only in 2014 and 2015, heirs have received the inherited pension capital (5 and 3 persons, respectively).

Contributions to private pension plans can be made not only by individuals as participants of the pension plans but also by employers 'Figure 2'. According to the law 'On Personal Income Tax' (PIT) if contributions to private pension plans are made by an individual person, it is possible to recover 20% of the PIT from the state, since the contributions are considered as eligible expenses. The recovery is possible every year for the previous calendar year and the amount of contributions may not exceed 10% of a person's gross income. Another condition is the limit of contributions - up to EUR 4000 per year (Par iedzīvotāju ienākuma..., 1993). Though, if the contributions exceed the set limits, the excess amount is included in the person's annual taxable income and the tax is calculated for this amount. If the contributions to the private pension plans are made by an employer, they are recognised as expenses related to the economic activity: thus, they are not a taxable object under the CIT (Uzņēmumu ienākuma nodokļa..., 2018). The law does not impose limits for the contributions but the employer shall make contributions for all its employees without any exceptions. The average amount of contributions made by an employer is EUR 65 per employee. There are companies that ensure combined contributions, i.e. these are contributions made by an employer together with a requirement that employees themselves make contributions to private pension plans.



Figure 2. Contributions made to private pension funds by pension plan participants in Latvia for 2013-2023. *Source: author's construction based on the Bank of Latvia data* (*s.a.*).

The largest amount of contributions made both by individuals and employers was achieved in 2021 when it accounted for EUR 106.51 mln of which EUR 16.61 mln or 15.60% were contributions made by employers. The increase might be explained by a slight recovery from the Covid-19 pandemic and pension plans participants growing awareness of the necessity to ensure future capital. Unfortunately, the next year marked a decrease in total contributions by EUR 10.29 mln or 9.66%. In 2022, the contributions made by individuals decreased (by EUR 12.84 mln or 14.28%), while contributions made by employers increased (by EUR 2.54 mln or 15.31%) compared with the year before. Geopolitical factors and growing inflation might serve as the main positive reasons for the change in participants habits. If previously private pension plan participants made rarer and larger contributions, then there are more regular and smaller contributions from 2022; thus, levelling out the market fluctuations (Citadele, 2023). The results for Q3 2023 also show a deteriorating trend. Although, as these are only data for three quarters, it is quite unlikely that the amount of contributions could exceed the results of 2022. The present analysis excludes pension fund contributions and other contributions as well as transfers from other pension funds and plans.

If the amount of contributions shows almost a linear growing trend up to 2021 followed by a decrease, then the amount of payments from the private pension plans demonstrates a quite fluctuating trend from 2017 'Figure 3'. The amount of payments includes additional pension capital paid out, pension payments in case of retirement and disablement and payments to heirs in case of death of pension plan members. The present research excludes transfers to pension plans, other pension plans and funds.

The ratio between contributions to and payments from the private pension plans has been steadily even up to 2017; yet, it was still positive till 2019. Afterwards the trend demonstrates expressive ups and downs. Hence, in 2019, payments from the private pension funds increased by 47.75%.



Figure 3. Contributions to and payments from the

private pension plans in Latvia for 2013-2023. Source: author's construction based on the Bank of Latvia data (s.a.).

The increase was almost equal for the two basic positions: additional pension capital paid out and payments in case of retirement (by 47.75% and 50.95%, respectively). The increase may not be associated with the increase in the number of retired pensions, as this number has decreased in 2019. This aspect could be reservedly attributed to the situation in 2021 when the amount of payments decreased by 33.50%; however, the number of retired persons dropped only by 1.81%. This means that mostly the changes in income and expenses of pension funds are associated with the changes in financial markets and habits of pension plan participants.

Geopolitical risks and high inflation followed by the reaction of financial markets in the world could be the reason for the growth of payments from pension plans by 94.80% and decrease of contributions by 9.66% in 2022 compared with the previous year. A decline was observed also in 2023. The proportion of additional pension capital paid out is 50% throughout the analysed period. Additional pension capital is a part of pension that is formed from savings of a pension plan participant in the pension funds.

The value of net assets of pension funds with a different speed grew up to 2021 followed by a decrease in 2002 and an increase again in 2023. Net assets value increased by 16.54% on average from 2013 to 2018 when a growth rate declined. In 2018, the situation in financial markets was unstable. Central banks in the world stopped the implementation of the expansive monetary policy (reduction of interest rates, redemption of financial instruments, etc.). Political crisis in Italy and devaluation of Turkish lira, uncertainty related to the trade market between the USA and China, fluctuations in financial markets of the developing countries, decrease in the bond rates in Germany (Luminor, 2019) served as factors impacting also the value of net assets of private pension funds.

Contributions made by private pension plans participants are invested in various financial instruments to diversify the risks and ensure the best way for the management of accumulated contributions 'Figure 4'. Moreover, the diversification of investments into capital and debt securities allows to mitigate fluctuations in the value of assets and increase the security of investments.



Figure 4. Investment portfolio of private pension funds in Latvia for 2013-2023.

Source: author's construction based on the Bank of Latvia data (s.a.).

Investment shares in investment funds compose the largest amount and proportion of the investment portfolio, i.e. 53.98% on average. The proportion of investment shares in investment funds has slightly fluctuated during the analysed period, reaching the highest proportion of 64.67% at the end of Q3 2023 and the largest amount of investments equalling to EUR 481.86 mln. Debt securities and other fixedincome securities compose the next largest segment of investments, i.e. 34.52% on average and accounting for EUR 223.08 mln at the end of Q3 2023. Investments in time deposits and other assets form minor proportions, i.e. 10% and 1.5%, respectively. Investments in other assets include shares and other variable-yield securities, investments in risk capital market, derivatives and investments in land and buildings. The diversification of investment portfolio, e.g., investment in real estate and other properties, help reduce the risk of fluctuations.

Geographical location of investments 'Figure 5' plays an essential role for proper placement of investment portfolio to ensure a profit of invested resources.



Figure 5. Geographical breakdown of pension plan investments for 2013-2023.

Source: author's construction based on the Bank of Latvia data (s.a.).

Geographical breakdown of pension plan investments demonstrates that the majority of investments are made in

the markets of the Western Europe. At the end of Q3 2023, the amount of investment in the Western Europe equalled to EUR 509 mln. The largest markets for investments are Ireland and Luxembourg (50% and 30% on average) in 2022 and 2023. At the end of Q3 2023, investments in these countries accounted for EUR 270.39 mln and EUR 161.05 mln, respectively. Estonia and Lithuania are the leaders for investments from the Central and Eastern Europe. The proportion of investment in Latvia has decreased from 38.37% in 2015 to 13.25% at the end of Q3 2023. Regardless of the proportional decline, the amount of investments has been stable - EUR 100 mln on average and at the end of 2023 it is expected to exceed the figure of 2022. Practically no investments have been made in financial markets of Russia from 2017 with the exception of 2021 when EUR 18 mln were invested there. Other markets include the USA, Canada, Asia and developing countries and investments in international financial institutions (in 2022 and 2023). Mexico, the USA and Bulgaria are relative leaders in this segment accounting for EUR 5-6 mln. Almost one-off investments have been made in the financial markets of Brazil (2015-2017), Peru (2019), Austria (2016), Slovenia (2013-2016), Switzerland (2016, 2022) and some other countries. Israel, Cyprus, Türkiye, Greece and Italy are among those countries where investments in financial instruments have not been made for the last three-five years.

The economic situation, the structure of investment portfolio and geographical location of investments are some of the factors impacting the performance of private pension plans. The improvement of the economic situation promotes interest of population to make savings in various financial instruments including contributions to private pension plans. Therefore, enlarging the value of assets to be invested in financial markets, while an appropriate placement of investments determines the return of pension plans 'Figure 6'. Moreover, the historical return of pension plans does not guarantee similar results in the future. The Finance Latvia Association calculates the return as a weighted average return based on the data of individual pension plans and the value of assets of these plans at the end of the period (manapensija.lv, s.a.). In other sources, the same association reports that the return is calculated as a compound result taking into account individual months of the period from the gross profit of the same period deducting commissions of asset managers and custodian banks but excluding commissions of private pension funds (Finance Latvia Association, 2021). The private pension funds calculate the return as the ratio of a pension plan's operating result to the arithmetic average value of assets for each month divided by the number of months per year. Hence, the return results may slightly differ depending on the data availability.

As demonstrated by Figure 6, short-term returns of private pension plans are very fluctuating with expressive increases and decreases. The correlation analysis determines the impact of inflation on returns of private pension plans. The calculated correlation coefficients report a negative moderate correlation between the analysed variables.





Source: author's construction based on the data from the Bank of Latvia (s.a.), manapensija.lv (s.a.), CBL (s.a.), INVL (s.a.), Luminor (s.a.), SEB (s.a.), Swedbank (s.a.).

The correlation between a long-term return and inflation is r = -0.6292, while it is r = -0.5138 between a short-term return and inflation. The coefficients of determination ( $R^2=0.40$  and  $R^2=0.26$ ) mean that the regression model explains only 40% and 26% of the variability. Therefore, it might be assumed that inflation has been a minor factor affecting the returns of private pension plans. Negative values of short-term return were reported in 2018 and 2022. In 2018, the decline in stock markets, turmoil related to Brexit and difficulties in trade markets mostly explain the fall of returns in short-term to a negative value, namely, -4.96%. Swedbank analysists report that the decline was experienced due to the imposition of tariffs on the goods from the EU and China, thus causing the socalled trade wars. The US Federal Reserve Bank continued to raise the base interest rate for USD and the ECB decided to slow down the injection of money into the economy (Swedbank, 2019). In contrast, the banks unexpectedly started a stimulating economic regime in 2019 which promoted price increase in stock markets and stabilisation of the economy.

The sharpest return decline was observed in 2022, when the arithmetic total average return of all private pension plans was -14.63%. Financial specialists and asset managers indicate that the decline had started already at the very beginning of 2022 even before the war in Ukraine, and it is explained by cyclical trends experienced in financial markets. The situation changed after 2021 which was a very successful year in financial markets basically thanks to the economic recovery from the recession caused by the Covid-19 pandemic. The year 2021 was especially successful for IT companies. Yet, in January-February 2022, investments were shifted from the IT sector to other sectors of the economy. Other reasons for the decline of return were the global downturn of stock markets and sharp growth of inflation (SEB, s.a). In 2023, the short-term return reached 11.03% in many aspects thanks to the decline of inflation. The falling inflation stimulated the activities of financial markets, since borrowing became cheaper and economic growth more active. In turn, this was reflected in higher prices of bonds and shares. Yet, population tends to invest in pension plans when they are the most profitable and withdraw the accumulated capital when the growth of pension plan return slows down. Therefore, short-term return is more subject to various financial shocks.

Opposite to expressive ups and downs in short-term returns, long-term returns show a positive growth through the entire period analysed, i.e. 4.16% on average. The lowest increase of long-term return was in 2022 (2.68%) due to the previously mentioned reasons. This means that a short-term decline of returns does not signal of future decrease in the amount of pension, since contributions to pension plans are considered to be a long-term investment.

The analysis of returns broken down by investment strategies of private pension plans demonstrate similar tendencies 'Figure 7', since the return highly depends on the situation and activities in the world financial markets.



plans in Latvia by investment strategies for 2013-2023. Source: author's construction based on the data from the Bank of Latvia (s.a.), manapensija.lv (s.a.), CBL (s.a.), INVL (s.a.), Luminor (s.a.), SEB (s.a.), Swedbank (s.a.).

Conservative plans are analysed from 2017, because one of the plans for which the data are available started the operation in 2015, while the other one only from 2021. Another reason for incomplete information on conservative pension plans is structural changes among pension plans provided by INVL pension fund by renaming and merging pension plans, and gradual transfer from conservative to balanced strategies. Similar changes were observed also in the segment of active 50% strategy plans. Merging and take-over processes of pension plans increase net assets value of the new plans and tend to offer more profitable return to pension plan participants. However, the data analysis of 'Figure 7' demonstrates moderate shortterm return development performed in all private pension plan strategies until 2017.

The most fluctuating return trends are demonstrated by the active pension plans in short-term, i.e. from -7.75% in 2018 to 16.52% in 2019 and from 15.77% in 2021 to -15.14% in 2022 and 13.46% again in 2023. Similar return trends are demonstrated also by balanced and conservative plans in short-term; though to a smaller extent. In long-term, balanced and active plans have maintained a positive return trend - the return of these pension plans has grown by 3.96% and 4.17% on average, respectively. Return of conservative plans has steadily grown from 2016 to 2020 (from -2.99% to 1.87%) and a sharp decrease was observed in 2023 (from 4.52% in 2022 to -3.39% in 2023). Conservative plans were the only plans which ended 2023 with a negative return; INDEXO Bond Index conservative plan due to its passive investment strategy may explain such a result.

#### Conclusions

- 1. The data analysis shows a steady increase (annually 6.24% on average) in the population participation in private pension plans. Active plan participants account for 51.42% on average, while the proportion of deferred participants is also large, i.e. 30.40% on average.
- 2. The economic situation, the structure of investment portfolio and geographical location of investments are among the factors impacting the performance of private pension plans. The majority of investments are made in the markets of the Western Europe. Contributions made by private pension plans participants are invested in various financial instruments to diversify the risks and ensure the best way for the management of accumulated contributions.
- 3. Short-term returns of private pension plans are very fluctuating with expressive increases and decreases where the most fluctuating return trends are demonstrated by the active pension plans. The sharpest return decline was observed in 2022, when the arithmetic total average return of all private pension plans was -14.63%. The basic reasons mentioned are the changes in investment portfolio, global downturn of stock markets and sharp growth of inflation.
- 4. Long-term returns show a positive growth through the entire period analysed, i.e. 4.16% on average. This means that a short-term decline of returns does not signal of future decrease in the amount of pension, since contributions to pension plans are considered to be a long-term investment.

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# ASSESSMENT OF FINANCIAL DISTRESS IN AGRICULTURAL COOPERATIVES IN LATVIA APPLYING THE PREVENTION SYSTEM INDICATORS

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### Abstract

Cooperation and financial stability of agricultural companies, especially small and medium ones, is very significant for the development of agricultural sector. In Latvia, cooperatives represent different sizes and industries: dairy, grain, fruit and vegetable, forest, agricultural services and home production. The research aim is to assess financial distress in agricultural cooperatives in Latvia by applying the prevention system indicators. The evaluation of financial indicators is based on the methodology developed by Deutscher Raiffeisenverband e.V. (DRV) - the leading association of agricultural and food industry cooperatives and cooperative-oriented companies in Germany. This system prescribes reporting and monitoring requirements for cooperatives to perform the preventive case analysis to ensure a successful operation of a cooperative or to prevent financial problems, if any. Therefore, financial indicators of cooperatives in Latvia were analysed adapting the DRV analysis methodology to the situation of Latvia to identify cooperatives requiring support to ensure viability.

The evaluation of cooperatives by the number of employees, assets, sales and other financial indicators convincingly demonstrates that the largest and most financially strong cooperatives in Latvia operate in the grain sector, followed by the dairy sector. The assessment of financial distress reports that 10 out of 51 analysed cooperatives experience risk of operation. The most common threat to a cooperative in Latvia is related to its equity; however, it is recommended to evaluate this indicator in line with other indicators, for example, changes in equity in recent years and length of a cooperative's operation. **Key words:** agricultural cooperatives, financial distress, prevention, performance indicators.

## Introduction

Agricultural cooperatives as cooperative societies providing services to producers of agricultural products play a significant role for the development of small and medium sized companies, since they can obtain higher value added for their products and ease the access to markets as well as to reduce costs, especially, transportation. Already at the beginning of the 1980s, Turtiainen & Von Pischke (1982) indicated that the financing system of cooperatives, though, having some common features, differ from other companies or organisations. The most essential difference lies in the characteristic that cooperatives depend on their membership; hence, expansion of cooperatives may be limited and they may become financially vulnerable (Turtiainen & Von Pischke, 1982). The same opinion is strongly emphasised also by a group of researchers who have examined agricultural cooperatives, their operation and financial situation several decades later. These researchers conclude that the principles and values of agricultural cooperatives are determining factors for the different financial analysis (Marcis et al., 2018; Pokharel, Archer, & Featherstone, 2020; Piccoli et al., 2020; Silva, Bagio, & Santos, 2022). Hence, Pokharel et al. (2019) examined the financial performance of agricultural cooperatives in the USA and came to a conclusion that profitability ratios differ in financially stressed and non-stressed cooperatives. However, the entire analysis indicated that smaller cooperatives may suffer from bigger financial stress compared with larger ones (Pokharel et al., 2019).

Slovak researchers Vavrek, Kravčáková Vozárová, & Kotulič (2021) consider that the financial analysis and diagnosis of critical situations of agricultural companies help highlight financial threats at an early stage of emergence. Similar arguments are expressed by

Lithuanian researchers who distinguish two groups of factors impacting the financial performance of agricultural companies, namely, economic and noneconomic ones (Stulpinienė & Aleknevičienė, 2012). The economic factors include liquidity, profitability, operating efficiency and other factors. Stulpinienė (2012) emphasises that financial distress is basically related to a non-qualitative farm. Maintenance and improvement of profitability and liquidity ratios as critical issues for the cooperative performance are also reported by Barton et al. (2011). Already in 1996, researchers have indicated on profitability as one of financial stress factors in agricultural cooperatives (Moller, Featherstone, & David, 1996). In Latvia, cooperatives differ by their size, value of assets, liquidity and profitability ratios and other financial indicators; thus, it is essential to provide the assessment of financial distress in these agricultural cooperatives to conclude on their viability potential. The financial distress evaluation is possible through the application of various methods; yet, the present research focuses on methodology developed by Deutscher the Raiffeisenverband e.V. (DRV), which is the leading association of agricultural and food industry cooperatives and cooperative-oriented companies in Germany. Hypothesis: the operational risk assessment of agricultural cooperatives in Latvia is possible via the application of the DRV preventive case analysis system. The research aim is to assess financial distress in agricultural cooperatives in Latvia by applying the prevention system indicators. The following tasks help achieve the set aim: 1) to characterise agricultural cooperatives in Latvia; 2) to analyse financial indicators of agricultural cooperatives. The terms cooperative and cooperative society are interchangeable in the research paper. The legal form of all analysed agricultural undertakings is a cooperative society; though, a term cooperative is used throughout the present research paper for the purpose of simplicity.

### Materials and Methods

The evaluation of financial indictors and prediction of financial distress in agricultural cooperatives is based on the methodology developed by Deutscher Raiffeisenverband e.V. (DRV). Section 7 of the Guidelines of the Cooperative Assistance Fund of the DRV (Richtlinien des Genossenschaftlichen ..., 2021) prescribes reporting and monitoring requirements for cooperatives to perform the preventive case analysis to

ensure a successful operation of a cooperative or prevent financial problems, if any. The DRV Guidelines determine several indicators for the evaluation whether a cooperative classifies as a preventive case under the preventive case analysis system criteria (Table 1). The system distinguishes two types of warning signals: yellow and red. The yellow signal indicates on initial problems in the cooperative operation if the indicators achieve and fall below the set limits, while the red signal requires urgent preventive actions to avoid critical performance situation.

Table 1

Group of	Indicators	Warning signals (thresholds)	
indicators		yellow	red
Assets value	Days sales outstanding (DSO)	> 60 days	-
Financial		< 20% <b>or</b>	< 10%
situation	Equity ratio (ER)	the main indicator (equity) has decreased by more	
		than 40% compared with the previous year	
Liquidity	Quick liquidity (QL)	< 50%	-
Profit	Return on equity (ROE)	< -10% or the main indicator (equity) has decreased by more than 40% compared with the previous year	< -20%
measures	Personnel expense intensity (PEI)	>70%	-
	Interest expense intensity (IEI)	> 70%	-
Qualitative	Management activities		
factors	Accounting policy		

The preventive case analysis system criteria and thresholds

Source: Rahmenbedingungen für Sanierungs ..., 2018.

Theory on financial analysis enlists various methods and indicators applied to study the financial position of a company which differ consistent with the target and necessity for the assessment of financial situation. The DRV highlights five key groups and eight indicators; however, qualitative factors including management activities and accounting policy are beyond the present research. The accounting policy can be partially evaluated by the appendix added to the annual report; while, a survey of the cooperative management allows to evaluate the management performance.

The value of assets is the first indicator under the preventive case system analysis. The formula for calculation of **days** sales outstanding (DSO) is as follows (1):

$$DSO = \frac{Average\ accounts\ receivable\ excluding\ prepaid\ expenses}{Net\ sales}\ x\ 365\ (1)$$

Days sales outstanding ratio shows the average number of days needed for a cooperative to collect payment after the sales have been made. The DSO ratio is considered to be optimal if it less than 60 days. The **equity ratio** (**ER**) or equity proportion of total assets (%) is the indicator showing the financial situation of a cooperative and it is calculated as follows (2):

$$ER = \frac{Total \ equity}{Total \ assets} \ x \ 100 \tag{2}$$

The proportion of equity in total assets shall be above 20%. If the equity ratio falls under 20% or the value of

equity has decreased by more than 40% compared with the previous year it signals on problems in the financial situation of a cooperative. If the ratio is below 10%, the situation is especially critical.

**Quick liquidity (QL)** ratio measures the ability of a cooperative to cover current liabilities with its quick assets deducting prepaid expenses. The DRV methodology envisages the expression of quick liquidity in per cent and it is calculated as follows (3):

$$QL = \frac{Current\ receivables - prepaid\ expenses + cash + current\ securities}{Current\ liabilities}\ x\ 100\ (3)$$

The ratio shall exceed 50%, i.e. a cooperative shall be able to cover its accounts receivable at least 0.5 times. Profit measures include three types of indicators: return on equity, personnel expense intensity and interest expense intensity.

**Return of equity (ROE)** measures the profitability of a cooperative related to its equity (4).

$$ROE = \frac{Retained \ earnings \ of \ the \ accounting \ period}{Equity} \ x \ 100 \ (4)$$

The indicator shall exceed -10% or the value of equity should not decrease by more than 40% compared with the previous year value. The cooperative experiences serious profitability efficiency problems if the ROE is below -20%. In general literature, the ROE shall range between 15-20%, so the DRV methodology allows even a negative result. Intensity of expenses is valued through two indicators: personnel expense intensity and interest expense intensity. These indicators allow to draw conclusions on the burden of personnel and interest costs and gross profit. **Personnel expense intensity (PEI)** indicator shows the personnel costs in relation to the gross profit of a cooperative. Personnel expenses encompass all payments made to employees and workers, namely, salaries, wages, social insurance contributions, vacation payments, bonuses and any other payments related to personnel. These expenses is the only information in terms of money found about personnel in the financial statements of a cooperative. The personnel expenses intensity is calculated as follows (5):

$$PEI = \frac{Personnel \ expenses}{Gross \ profit} \ x \ 100 \tag{5}$$

The DRV methodology sets the minimum limit for personnel expense intensity ratio of 70%. However, other sources acknowledge a lower minimum of 50% on average (REFA International ..., s.a.) distinguishing the ratio between production and service companies, i.e. 30% and 60%, respectively.

**Interest expense intensity (IEI)** indicator measures the costs of interest payment related to the gross profit. The indicator is calculated as follows (6):

$$IEI = \frac{Interest \ expenses}{Gross \ profit} \ x \ 100 \tag{6}$$

Similar to the personnel expense intensity indicator also for the interest expense intensity indicator the DRV methodology sets the minimum limit of 70%.

The evaluation of all these indicators included in the prevention case analysis system help determine whether the existence of a cooperative is not endangered, financial problems are likely to occur or the system signals that a cooperative has fallen into the area of observation limits. The cooperative has reached a precaution threshold if it produces a 'red signal' in one of the key indicator groups or at least one of the key indicators has a 'yellow signal' in three different groups.

#### **Results and Discussion**

*Characteristics of agricultural cooperatives in Latvia* The Association of Agricultural Cooperatives of Latvia (LLKA) unites more than 50 cooperatives representing different sizes and industries: dairy, grain, fruit and vegetable, forest, agricultural services and home production. The LLKA is aimed to create a favourable environment for the development of agricultural cooperatives in Latvia, to help solve various problems of its members, to attract financing for the implementation of cooperatives' investment plans and needs in order to promote the growth, sustainability and financial stability of cooperatives.

The attraction of financial resources from commercial banks and other financial institutions or credit unions are often limited by the offered interest rates and guarantee requirements, especially for small and medium-sized cooperatives. In addition, the equity and other financial indicators of cooperatives are often not good enough to receive a loan. A positive aspect in the implementation of investment projects is the European Union financing available through the Rural Development Programme. However, it is available only to those cooperatives that are annually evaluated consistent with the Compliance Conditions of Cooperative Societies and have received a compliance status. Fifty agricultural cooperatives have received the compliance status in 2022 and 2023.

The following analysis was carried out for 51 agricultural cooperatives (Table 2), which have received the compliance status and/or are the members of LLKA, and were not liquidated on 31 December 2023.

Table 2

Characteristics of			in Zat i la sa sje		<b>1 u u u u u u u u u u</b>	= = = = =
Sector		Dairy	Grain	Fruit, vegetables	Meat	Other
Number of cooper	ratives	22	16	6	2	5
	min	1	0	1	0	1
Number of employees	max	92	219	11	1	4
	average	12	27	4	1	2
	min	28 293	27 840	32 024	15 050	40 765
Assets, EUR	max	4 608 624	126 349 464	1 918 851	67 680	498 330
	average	943 980	15 207 845	766 992	41 365	161 456
	min	232 718	167 366	30 117	442 053	3729
Sales, EUR	max	41 796 430	339 132 526	1 046 728	518 072	164 610
	average	5 917 676	39 509 067	1 200 974	480 063	85 154
	min	-138 597	-3099	155	-15 509	-126 776
Profit, EUR	max	291 654	4 762 256	156 107	5923	23 836
	average	59 533	573 778	46 638	-4798	-20 341
	min	22 790	12 582	12 817	-8697	1325
Equity, ER	max	2 539 232	29 894 190	6258 179	4165	489 090
	average	157 650	4 010 009	208 352	-2266	121.858

Characteristics of agricultural cooperatives in Latvia subjected to the financial analysis in 2022

Source: authors' calculations based on Lursoft data.

According to the number of employees, assets, sales and other financial indicators, the largest and most financially strong cooperatives in Latvia represent the grain sector, followed by the dairy sector. In recent years, cooperation has also been developing well in the fruit and vegetable sector, while weaker results are reported by the cooperatives of meat and other sectors. However, the range of performance indicators and results of individual cooperatives is very large in all sectors (Table 2).

The dairy sector represents the largest number of cooperatives. In 2018, the first Level 2 cooperative was established in Latvia, namely, the *cooperative* society of agricultural services Baltu piens, which unites ten cooperatives of raw milk producers. The analysed 22 dairy cooperatives differ in the range of services they offer to their members as well as whether they are engaged only in the purchase and sale of products or they also provide processing of products. Therefore, cooperatives are very different in size and have financial results of a wide range. For example, a dairy cooperative Straupe has the largest number of employees and the largest equity, since its operating activities include also milk processing, cheese production and sales in 16 sales outlets. On the contrary, the majority of cooperatives deal mainly with the purchase and resale of milk to processing companies. Four dairy cooperatives ended the year 2022 with a loss; yet, a cooperative Nadzini 1 experienced the worst situation (loss equalling to EUR 138.6 thou. in 2022 and EUR 67.5 thou. in 2021). Hence, the decrease of its equity is very sharp (by 86%).

Also, 16 grain cooperatives have very different size and financial indicators. The largest cooperatives are developing very rapidly by increasing the number of members, expanding the range of services, finding the best markets for the sale of products at the best prices (e.g., Latraps, VAKS, Durbes grauds). However, there are also small grain cooperatives that unite only a few farmers (Vandzenes agro and Akots). Both small cooperatives have closed the last two years with a loss; other financial indicators are deteriorating therein.

The six fruit and vegetable cooperatives have very different specialisations and scales. All these cooperatives have earned profit in 2022; hence, they were able to increase their equity. A cooperative Bio Berries Latvia, founded in 2019, has very good growth indicators. Both meat cooperatives are new (founded in 2021) and their operating results are different. Worse results are demonstrated by GreenBeef.lv, whose sales have increased 2.2 times in 2022 compared with 2021 but this increase coincides with the growth of loss. Therefore, the year 2022 was closed with a negative equity of EUR 2200.

The analysed cooperatives of other sectors unite beekeepers (2), providers of agricultural services (2) and home producers (1). A cooperative providing agricultural services Medotava, founded in 2017, which deals with the purchase and sale of honey, shows the best results and the fastest growth. While the other honey cooperative Kurland Honey does not have such good results, as its sales decreased by 61.5% in 2022 compared with 2021 and the year was closed with a loss. Even worse results are reported by a cooperative providing agricultural services Bauņi, whose sales decreased by 93.5%, and the year was closed with a loss and a reduced equity.

# Financial analysis of agricultural cooperatives based on the DRV methodology

The financial indicators of all LLKA members were analysed adapting the DRV analysis methodology to the situation of Latvia to identify cooperatives requiring support to ensure viability.

Days sales outstanding ratio. In 2022, dairy and meat cooperatives did not encounter problems with the recovery of receivables, which means that these cooperatives timely collected payment for the delivered products. In contrast, for seven cooperatives of other sectors, the threshold value of this indicator exceeded the critical 60-day limit (yellow signal). For some fruit and berry cooperatives, the settlement period exceeded even 200 days on average. However, according to the DRV methodology, this indicator alone does not pose a critical threat to the viability of the cooperative, since it shall be assessed in line with other indicators.

Equity ratio. Three dairy cooperatives, one grain and one vegetable cooperative have an equity ratio less than 20% (yellow signal), which is not assessed as a threat. Seven cooperatives of which two dairy cooperatives: Nadziņi 1 (3.6%) and Baltu Piens (9.4%), one grain cooperative Ošenieku grauds (8.1%), the two cattle cooperatives: Latvijas Liellops (6.2%) and GreenBeef.lv (-57.8%), one honey cooperative Kurland Honey (5.2%) and a cooperative Kuldīgas labumi (3.3%) have a ratio of less than 10% (red signal). In addition, the analysis determines also the evaluation of the change in equity compared with the previous year (%) ( $\Delta$ equity). The yellow threshold signalling that the indicator has decreased by more than 40% is reported by Nadzini 1 (-86.0%); thus, indicating on a significant deterioration of the situation. The cooperative has operated with a loss for the previous two years. As a result, the cooperative's equity has decreased significantly. The size of equity has also critically decreased for cooperatives Piebalga (-43.4%) and Piena āre (-40.3%); however, the situation is not so dramatic, as these cooperatives ended at a loss only the year 2022. The equity of a cooperative Piebalga decreased just by 1.6% due to the loss (EUR 9.5 thou.), while the loss of the cooperative Piena āres (EUR 39.3 thou.) significantly reduced the equity - by 36.0% at the end of 2022 compared with the beginning of the year.

**Quick liquidity.** According to the DRV methodology, none of the analysed dairy cooperatives has a critical quick liquidity ratio, as the total amount of current receivables and cash is not less than 50% of current payables. Three grain cooperatives and a cooperative

Kuldīgas labumi have the liquidity ratio below the set rate; however, this indicator alone does not pose a critical threat to the viability of the cooperative, as it shall be evaluated in line with other indicators.

**Return on equity.** Similar to the equity ratio, this indicator is also very critical for cooperatives: Nadziņi 1 (-608.1%) and Piena āres (-56.2%). Moreover, these cooperatives have reached the threshold of red warning signal, since the ratio is below -20%. In contrast, a cooperative Baltu piens, which had a critical equity ratio, has a positive and sufficient ROE (54.4%). In addition, the analysis of the changes of profit of the accounting period (%) ( $\Delta P$ ) demonstrates that a cooperative Nadzini 1 has been experiencing a critical situation for the previous two years, as the loss has doubled (EUR 67 thou. in 2021 and EUR 139 thou. in 2022). A yellow ROE threshold was highlighted also for two grain cooperatives but, as mentioned before, this indicator alone does not pose a critical threat to the viability of the cooperative, since it shall be assessed in line with other indicators.

**Personnel expense intensity.** It is possible to calculate this indicator only for six cooperatives, as the other cooperatives do not enclose information on personnel expenses in their annual reports. The personnel expenses intensity ratio exceeds the limit set by the DRV methodology and corresponds to the yellow signal for four cooperatives. Again, this indicator alone does not pose a critical threat to the viability of the cooperative and it shall be evaluated in line with other indicators. The evaluation of this indicator for other cooperatives is possible only if cooperatives have identified data on personnel expenses. The majority of cooperatives (47 out of 51) classify expenses in the profit or loss statement according to the function of expenses, where personnel expenses

are not shown separately, as expenses are classified into production, sales and administration expenses. The application of the DRV methodology is possible only if a profit or loss statement is classified by the type of expenses or personnel expenses are decoded in the annex to the annual report of a cooperative.

**Interest expense intensity.** In 2022, less than half of cooperatives (23) disclosed interest payment expenses in their annual reports. In total, six grain cooperatives have significantly exceeded the limit value (70%) or reached the yellow signal. The indicator is negative for two cooperatives: Vandzenes agro (-137.1%) and Raibaļas (-922.6%). A cooperative Raibaļas is in a particularly critical situation, as the interest payments are relatively large (EUR 2.4 thou.) and the year was closed with a loss of EUR 261. It is positive that the interest payments and loss of this cooperative are decreasing compared with the previous year as well as the equity ratio is slightly increasing but it is still not sufficient (12.8%).

Results of the analysis demonstrate that the operation of 10 out of the 51 evaluated cooperatives were found to be endangered consistent with the financial results of 2022. Moreover, nine of them report at least one red signal (Table 3). The table also includes the company rating given in the Lursoft database. The rating is calculated by evaluating the main indicators characterising the financial activity of each company: solvency (weight in the rating 30%), profit before taxes (20%), liquidity (20%), increase of sales (10%), return on equity (10%) and liabilities (10%). The rating for the company is created both in the industry and among all companies registered in Latvia. Total rating is the average arithmetic index between the rating in the industry and the rating among all companies in the country. The rating ranges on a scale from 1 (poor) to 5 (good).

Table 3

						-			
Industry	Cooperatives with endangered operation	DSO	ER	$E\Delta$	QL	ROE	PΔ	IEI	<i>Lursoft</i> rating
	Baltu piens*	15.8	9.4	121.4	125.0	54.4	142.2	0.0	2.9
Dairy	Nadziņi 1*	22.1	3.6	-85.9	77.9	-608.1	105.4	0.0	1.3
	Piena āres	17.2	19.0	-36.0	123.4	-56.2	-229.1	0.0	1.7
Grain	Ošenieku grauds	33.2	8.1	7.0	91.1	5.6	-15.3	650.2	2.2
	Vandzenes agro	106.7	14.9	-1.2	108.1	-1.1	56.0	-137.1	1.2
Mant	GreenBeef.lv	6.8	-57.8	-227.5	53.2	178.4	17.8	0	1.4
Meat	Latvijas liellops	25.6	6.2	251.0	188.9	142.2	143.1	0.1	3.5
Fruit, vegetables	None of	cooperatives l	has been id opera	dentified as ution or dev	possible to elopment	o encount	er a threa	at to its	
	Kurland Honey	132.3	5.2	21.2	105.5	-45.1	-248.6	0	1.6
Other	Bauņi**	24 108.3	98.1	-20.7	2 548.8	-25.9	-268.6	0	2.5
	Kuldīgas labumi	6.5	3.3	364.9	7.9	77.3	-105.9	395.1	2.7

Agricultural cooperatives of Latvia demonstrating endangered operational activity consistent with the DRV methodology by the financial results of 2022

\* not a member of LLKA, \*\* no compliance status. Source: authors' calculations based on Lursoft data.

It is very positive that none of the six fruit and vegetable cooperatives shows critical results after the financial results of 2022. Some yellow signals point to the fact that a cooperative Mūsmāju dārzeņi should increase the equity ratio, a cooperative providing agricultural services Augļu nams should speed up the circulation of receivables, a cooperative providing agricultural services Baltijas ogu dārzi should reduce personnel expenses and promote the increase of profit, as its profit has decreased from EUR 24000 to EUR 2000 compared with 2021.

Out of the 16 analysed grain cooperatives, two were found to be at risk of operation. A cooperative providing agricultural services Ošenieku grauds is one of them, since its equity ratio is less than 10%; however, it has slightly increased (from 7.0% to 8.1%) compared with 2021. Only one grain cooperative - a cooperative providing agricultural services Vandzenes agro has received three yellow signals: DSO, ER and profit, as the last two years were closed with a loss.

In 2022, the worst results were observed for meat cooperatives and those representing other agricultural sectors. The two meat cooperatives received a red signal for the equity ratio - Latvijas liellops (6.2%) and GreenBeef.lv (-57.8%). A cooperative Latvijas liellops has improved its indicators compared with 2021. If the cooperative closed the year with a loss and had a negative equity in 2021, then it has earned a profit of EUR 5923 in 2022. In addition, the cooperative has increased its equity by EUR 1000 and reached a positive figure for the equity. In contrast, a cooperative providing agricultural services GreenBeef.lv closed the last two years with a loss and, hence, it has a negative equity of EUR 8697 at the end of 2022 as well as its liabilities exceed its assets by 57.8%.

In the group of other cooperatives, three out of five cooperatives show a significant decrease in revenues. A beekeeping cooperative Kurland Honey closed the year 2022 with a loss, which resulted in a negative return on equity (-45.1%) and a critically reduced equity (by 5.2%). Positively that the cooperative has increased its share capital and reserve compared with the previous year. The ROE of an agricultural services cooperative Bauni also corresponds to the red signal; however, the large ER (98.1%) significantly improves the situation. The DSO is critical, since the amount of

receivables significantly exceeds the sales. Moreover, the annual report does not provide sufficient information for the evaluation of financial data. The ER (3.3%) is critical for a home manufacturer cooperative Kuldīgas labumi; nevertheless, it has increased the ER compared with the previous year, as the year 2022 was closed with a profit. Only two cooperatives of this group do not report problems with the development or a threat to their operation: a cooperative providing agricultural services Jeru mašīnu rings and a beekeeping cooperative Medotava, which have shown relatively good results.

The comparison of Lursoft rating and the evaluation results obtained by the research authors show that some cooperatives have received a good evaluation in the Lursoft rating, for example, cooperatives Latvijas liellops (3.5) and Baltu piens (2.9). Although, both cooperatives have received a red signal for their equity ratio according to the DRV methodology. Sufficiently good other financial indicators explain this situation, so it can be concluded that the fact that the equity ratio is less than 10% does not always pose a threat to the future operation of a cooperative. Calculations made consistent with the DRV methodology show that exactly the equity ratio poses the greatest threat to cooperatives in Latvia; though, it is recommended not to evaluate this ratio alone but in line with other indicators, such as the structure of equity and changes in equity in recent years as well as the length of a cooperative's operation. Several of cooperatives listed in Table 3 are new.

The breakdown of agricultural cooperatives by regions (Table 4) demonstrates that the largest number of cooperatives, furthermore these are cooperatives representing various sectors, operate in Vidzeme (18). The most of cooperatives facing operational threats (4 out of 12) operate in Kurzeme. Dairy (6) and grain (5) cooperatives mainly operate in Zemgale. There are significantly fewer cooperatives in Latgale (5). In addition, two of them can be identified as operationally endangered according to the financial analysis. There are also fewer cooperatives in Pieriga, which can be explained by a smaller share of the agricultural sector in the region. Operatives in Pieriga; the situation is relatively better also in Vidzeme and Zemgale.

Table 4

Breakdown of agricultural cooperatives by regions and operational threat in Latvia according to the
financial results of 2022

Region	Da	airy	Gr	Grain		Vegetables		Meat		Other		Totally	
	total	probl.	total	probl.	total	probl.	total	probl.	total	probl.	total	probl.	
Vidzeme	7	no	6	no	2	no	1	1	2	1	18	2	
Zemgale	6	1	5	no	1	no	no	no	1	1	13	2	
Kurzeme	6	1	4	2	1	no	no	no	1	1	12	4	
Latgale	3	1	1	no	no	no	1	1	no	no	5	2	
Pieriga	no	no	no	no	2	no	no	no	1	no	3	no	
Total	22	3	16	2	6	no	2	2	5	3	51	10	

Source: authors' calculations based on Lursoft data.

The evaluation of the results by the size of cooperative allows to conclude that micro (5) and small (5)

cooperatives have worse results, while medium and large ones have better results (Table 5).

Table 5

Breakdown of agricultural cooperatives by sector, size and operational threat in Latvia according to the financial results of 2022

Sizo	Dairy		Gı	rain	Vege	tables	Μ	leat	Ot	ther	Totally	
Size	total	probl.	total	probl.								
micro	7	no	4	no	4	no	2	2	5	3	22	5
small	13	3	7	2	2	no	no	no	no	no	22	5
medium	2	no	3	no	no	no	no	no	no	no	5	no
large	no	no	2	no	no	no	no	no	no	no	2	no

Source: authors' calculations based on Lursoft data.

There are only two grain cooperatives in the group of large cooperatives: Latraps in Zemgale and VAKS in Vidzeme. Medium cooperatives are represented by five cooperatives and none of them has endangered operation. The size of a cooperative (company) is determined under the criteria prescribed by the Law on Annual Financial Statements and Consolidated Financial Statements, when evaluating the value of assets, sales and the average number of employees in the cooperative.

#### Conclusions

- 1. The evaluation of cooperatives by the number of employees, assets, sales and other financial indicators convincingly demonstrates that the largest and most financially strong cooperatives in Latvia operate in the grain sector, followed by the dairy sector. In recent years, the cooperation is also developing well in the fruit and vegetable sector, while weaker results are reported in the meat cooperatives and cooperatives representing other agricultural sectors. Yet, the range of performance indicators and results of individual cooperatives is very large in all sectors.
- 2. A complete application of the DRV methodology for the evaluation of the performance indicators of cooperatives requires the data on personnel expenses included in the profit or loss statement, which is classified by types of expenses. Another option is the identification of personnel expenses in the annex to the annual report of a cooperative.
- 3. The DRV methodology envisages also the evaluation of two qualitative indicators: cooperative management activity and accounting

policy. The accounting policy can be partly assessed using the appendix added to the annual report; but small cooperatives do not have to prepare it, so the accounting policy may not be assessed by the annual report. The management performance may be assessed by conducting a survey of the cooperative management.

- 4. Calculations made consistent with the DRV methodology show that 10 out of 51 analysed cooperatives experience risk of operation. The most common threat to cooperatives in Latvia is the equity ratio (9 cooperatives); however, it is recommended to evaluate this indicator in line with other indicators, for example, changes in equity in recent years and the length of a cooperative's operation.
- 5. In Latvia, the largest number of cooperatives of various industries operate in Vidzeme (18), while mainly milk (6) and grain (5) cooperatives operate in Zemgale. In Kurzeme, relatively more cooperatives face operational threats (4 out of 12). There are significantly fewer cooperatives in Latgale (5), and two of them were found to be operationally threatened. There are also fewer cooperatives in Pieriga (3), none of them has been found to be in danger of operation, the situation is relatively better in Vidzeme (operationally endangered are 2 out of 18) and Zemgale (respectively 2 out of 13).
- The evaluation of the results by the size of cooperative allows to conclude that micro (5) and small (5) cooperatives have worse results, while medium and large ones have better results.

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# EVALUATION OF SCENARIOS FOR THE IMPROVEMENT OF SOCIAL PROTECTION FOR FAMILIES WITH CHILDREN IN LATVIA

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### Abstract

Social protection for families with children is one of the priorities Latvia has highlighted in its strategic planning documents. Moreover, the priority being advanced for several planning periods indicates on the necessity to improve social security and foster the birth rate in the country. The research aim is to develop priority scenarios for possible improvement of social protection for families with children in Latvia. The authors put forward four scenarios for the improvement of social protection for families with children in Latvia, of which the experts in the field recognised the replacement of the personal income tax relief for children with a larger family state benefit as the priority. This would ensure fairer support for all families with children, including those on low incomes. Also, increasing the minimum wage and reducing the shadow economy would improve the social protection of families with children. Evaluating the criteria of population interests, the experts recognised the increase of family social security as more important than the increase in the number of children in the family, as the increase of social protection would contribute to the increase in the number of children in families thereof.

**Key words:** social protection, social benefits, support for families with children, state family allowance, personal income tax relief.

## Introduction

The strategic planning documents of Latvia put forward social protection of the population as one of the priorities for several planning periods. The improvement of social security and increase of financing for the social sphere is vitally significant to achieve the increase of the quality of life of the population and to stimulate the birth rate in the country (Latvijas ilgtspējīgas attīstības ..., 2010).

'Strong families in generations' is one of the courses of action envisaged in the National Development Plan of Latvia for 2021-2027 (2020). The mentioned course of action is targeted on the improvement of the support system for families with children, at the same time encouraging families to give birth to a second child and create large families. The population of Latvia positively evaluates the present system established to support families with children; nevertheless, they indicate on the necessity to improve the system so that the level of income per family member does not essentially decrease due to the birth of a child (Latvijas Nacionālais attīstības ..., 2020).

Also the guidelines 'On Social Protection and Labour Market Policy Guidelines for 2021-2027' (2021) mark the reduction of income inequality and poverty of the population as well as the promotion of employment as one of the targets. Sustainable, stable and adequate material support for families is required to achieve the set target. The development of the state and municipal material support should be planned so that social transfers are adequate and financially sustainable and so that they do not reduce the motivation to enter the labour market.

Kristapsone & Kantane (2019) state that the surveyed population of Latvia recognise the importance of the improvement of social protection by increasing social benefits in order to enhance the well-being of families. Grinevica, Bite, & Broka (2022) also agree to the statement that childcare allowances are essential support for families with children; hence, it is required to proceed with the improvement of the support system for families with children, consequently reducing poverty and improving the harmonisation of family and work life. In contrast, Ciobanu (2017) indicates that even nowadays those families that have many children frequently suffer from discrimination and other social and economic difficulties caused by low income.

Research hypothesis – social protection for families with children is diverse in Latvia, yet it requires improvements in line with the economic situation in the country. The research aim is to develop priority scenarios for possible improvement of social protection for families with children in Latvia.

The authors have advanced the following research tasks to achieve the set aim:

- 1) to evaluate social protection for families with children in Latvia;
- 2) to determine the most appropriate scenario for increasing social protection for families with children based on the opinion of experts.

#### **Materials and Methods**

Research methods: the monographic and descriptive methods, analysis and synthesis, the graphic method, statistical method. The Analytic Hierarchy Process was applied to determine the key stakeholders (residents, municipalities and the national government) interested in enhancing social protection for families with children in Latvia, based on ratings by experts, to assess the criteria that were important for each of the stakeholders as well as to identify the most suitable scenario for a further enhancement of social protection. The present research is based on various scientific publications, publicly available documents, information available on databases and other sources.

#### **Results and Discussion**

State social protection for families with children in Latvia

Abolina (2016), analysing the theoretical framework of social support measures by Math & Thevenon, emphasises that it is possible to provide support measures for families in different ways, for example, by granting financial support, childcare leave or support in the form of services. Within the framework of the present study, the authors focus on financial support for families with children, which is implemented through social transfers or other forms of support. Social transfers include pensions, benefits and maintenance.

An important part of social transfers is the benefit system, which is divided into three large groups. The first group includes social insurance benefits, the second group refers to the state social benefits and the third group covers social assistance benefits.

State social insurance benefits, which are related to the birth of a child and sickness, are maternity, paternity, parental and sickness benefits. Their amounts depend on the insurance salary contributions of a person, i.e. work remuneration. Yet, education is one of the most important factors determining the amount of salary (Darba algas un ..., 2006). Higher salaries are earned by those employees who have higher level of education (Career Profiles, s.a.). Also Mistre, Zvaigzne & Mazure (2019), conducting a population survey in Latgale region, found that education is one of the most important individual factors affecting the level of wages and salaries. The importance of education is also confirmed by the research on a conducted survey of experts in 2022 (Mistre, Leibus, & Mazure, 2023a).

A person's social protection is also impacted by undeclared employment (including 'envelope wages'), the mandatory state social insurance since contributions are not made in full amount from wages, and this affects the amount of state social insurance benefits and pensions. The study 'Shadow Economy Index in the Baltic States 2009-2021' reports envelope wages as the most significant component of the shadow economy in the Baltic States in 2021, respectively envelope wages accounted for 46.2% of the total shadow economy in Latvia, 42.7% in Estonia and 38.8% in Lithuania. In 2021, undeclared income in Latvia amounted to 30.0% of the total shadow economy, while the component of undeclared employees - 23.8% (Sauka & Putnins, 2022). Putnins and Sauka (2015) accentuate a vicious circle of the shadow economy: individuals work illegally and do not pay taxes; thus, revenue in the state budget decrease and an increase in tax rates is necessary, which further encourages unofficial employment and weakens the economic and social basis.

Workers who officially receive at least the minimum monthly wage are more socially protected, because larger social insurance contributions are made as the minimum wage increases, and, consequently, the amount of social insurance benefits also increases. Several studies demonstrate that the well-being of lowincome earners improves with the increase of the minimum monthly wage. Ferrarro, Merikull & Staehr (2018) have come to the conclusion that the minimum wage contributes to the reduction of wage inequality, especially in segments of the labour market with dominating low wages. Flavin & Shufeldt (2017) have also found that the level of well-being of low-income citizens improves with the increase of the minimum monthly wage.

The next group of benefits are **state social benefits**. The support for families with children includes the following benefits: state family allowance, childcare benefit, childbirth allowance and benefits for care of children with disabilities.

The state social benefits system includes both regularly paid benefits and one-off benefits. However, most social benefits are mainly intended to cover the needs for the first year of a child's life, without providing child care opportunities in the following childhood years and covering additional family expenses during the school years. Only the state family allowance provides support to the family for almost the entire period of raising and schooling the child (Koncepcija par ģimenes ..., 2012).

Mistre, Leibus, & Mazure (2023b) report that the amounts of state benefits for maternity, paternity, parents and family have increased in Latvia from 2011, while the amount of the childcare benefit has not been changed since 2014. Moreover, the amount of the childbirth allowance has not been changed even for a longer period, i.e. since 2004. Hence, the amounts of these benefits do not correspond to the current economic situation in the country.

Also, **social assistance benefits**, which are paid by the municipality where the claimant has declared its place of residence are an important type of benefits. The council of each municipality may adopt binding regulations, which determine the benefits of the voluntary initiative (Pašvaldību likums, 2022).

No less important type of social transfers is **maintenance** intended to cover the monthly maintenance expenses of a child. The minimum amount of maintenance is determined by the government (Uzturlīdzekļu garantiju fonda ..., 2016). It is the duty of every parent to provide maintenance for the child, regardless of the state of his or her property and ability to support the child.

**Other types of support** for families with children can be provided in the form of tax reliefs or social services (such as services related to the childcare and education). In accordance with the law 'On Personal Income Tax' (1993), personal income tax (PIT) relief is applied in Latvia for each dependent person. The amount of this tax relief is EUR 250 per month from 2020 (Noteikumi par neapliekamā ..., 2017). Calculations demonstrate that this tax relief is unfair in relation to those families where the child's parents receive the minimum wage (EUR 700 per month in 2024). In that case the taxable income is less than the amount of the non-taxable minimum, and the relief cannot be applied in the salary calculation. Moreover, inequality increases precisely in those families with children, where parents' wages are lower, and there are several children in the family (Table 1). When receiving the average salary in Latvia, which was EUR 1373 per month in 2022 (Official Statistics Portal, 2023), the PIT relief is used if there are four children in the family but if the family has five or more children, then this relief is not being used to the full extent. A particularly bad situation develops in families where a child is raised by one parent or both parents receive the minimum wage.

Table 1

Amount of personal income tax relief depending on the number of children in the family	
and remuneration in Latvia in 2023, EUR	

	Doliof	Gross work remuneration/non-taxable minimum									
Number of children	amount per	620 EUR / 500 EUR	800 EUR / 400 EUR	1000 EUR / 300 EUR	1373 EUR / 200 EUR						
	month	Unused amount of PIT relief (-) or used amount (+)									
one	250	-195.10	+250	+250	+250						
two	500	-445.10	-184	+500	+500						
three	750	-695.10	-434	-155	+750						
four	1000	-945.10	-684	-405	+1000						

Source: authors' construction and calculations.

The Ministry of Welfare in its informative report '*On the Situation of the Minimum Wage in 2022*' (2023) indicates that 18.1% of employees had income equal to the minimum wage or less in 2020, while these were 19.4% of employees in 2021, which shows that this situation worsens. It should be emphasised that the minimum wage in Latvia was the second lowest in the EU in 2022, and it is also lower than in Lithuania and Estonia.

The study 'Conducting Research on the Factors Influencing the Regeneration of the Nation' (2013) reports that if there is an intention to apply the PIT relief for a dependent persons as a tool to increase the birth rate, the relief should be differentiated depending on the number or the sequence of children. At the same time, it is emphasised that some families are not able to use the benefits to their full extent, and thus, the increase in the PIT relief would not provide support to families with many children and would not promote birth. According to Urban & Peezer (2018), tax incentives (reliefs) might be attractive thanks to the simplicity of their administration; however, these advantages are criticised for their 'regressive' effect, as they do not always reduce poverty in families. It can be concluded that the PIT relief is not fair for all families with children; hence, it is necessary to find out the best solution for improving social support, so that it is fairer and corresponds to the economic situation of the population.

# Development scenarios for social protection for families with children in Latvia

The authors have employed the Analytic Hierarchy Process (AHP) to identify the most appropriate scenario for enhancing social protection for families with children in Latvia. Based on the previous research, a pyramid of hierarchies was created, which was divided into four levels 'Figure 1'.



Figure 1. Hierarchy of evaluation criteria for enhancing social protection for families with children in Latvia. *Source: authors' construction.* 

At the *first level*, a general target is defined enhancement (improvement) of social protection for families with children in Latvia. The *second level* includes criteria groups or stakeholders interested in enhancing social protection for families with children. The selection of criteria groups was based on the question: for whom is it important to enhance social protection for families with children in Latvia? The *third level* defines the evaluation criteria that are important for each of the stakeholders. Four potential scenarios (alternatives) for increasing social protection for families with children in Latvia, which experts need to rate in terms of criteria of the second and third level groups, are suggested at the *fourth level*.

**Scenario 1**: increasing the minimum monthly wage and salary. By increasing the minimum monthly remuneration, an individual's insurance salary contributions increase, which, in turn, determine the sizes of social insurance benefits (maternity, paternity, parental, sickness). By increasing the minimum monthly wage and salary, social protection for persons from lower income families increase in the event of one of the social risks.

**Scenario 2**: retaining the PIT relief on children and gradually increasing the amount thereof. By increasing the PIT relief for a dependent child, family income increases. However, individuals earning the minimum monthly wage or salary cannot use this tax relief in full. Therefore, this kind of support is not equally fair to all families with children.

**Scenario 3**: replacing the tax relief on children with a larger family benefit to provide fairer support for all families with children, which is not affected by the parents' income.

**Scenario 4**: decreasing the shadow economy. By reducing undeclared employment, an individual gets involved in the social insurance system, which increases tax revenue paid to the national and local government budgets and thus social protection for the individual increases. Social protection for the individual increases by reducing the 'envelope wages'. To evaluate the potential scenarios (alternatives) for enhancing (increasing) social protection for families with children, seven experts who were competent in the field of social protection and represented various stakeholders were involved:

- deputy director of the Social Policy Planning and Development Department of the Ministry of Welfare;
- deputy director of the Children and Family Policy Department of the Ministry of Welfare;
- head of the Methodological Management Department of the State Social Insurance Agency;
- 4) adviser to the Association of Local and Regional Governments of Latvia on health and social issues;
- 5) consultant to the State Development Planning Division, Cross-Sectoral Coordination Department of the State Chancellery;
- 6) deputy chairperson of the Free Trade Union Confederation of Latvia;

7) head of the parental organisation 'Mammamuntetiem.ly' of Latvia.

A survey questionnaire was sent to each expert and a remote meeting was held to help them fill in the matrices and discuss problems in the field of social protection related to support for families with children. After processing the experts' ratings, it could be concluded that the most important were population interests, i.e. the interests of families with children, for increasing social protection for families with children 'Figure 2'.





According to the experts, the state and local governments were the least interested stakeholders in increasing social protection for families with children. After rating the second-level criteria groups, the experts had to rate the third-level criteria groups, where three criteria were set for each interest group. After summarising the expert opinions on criteria for population interests, it could be concluded that the enhancement of social security for the family was rated the highest. This was evidenced by an arithmetic mean calculated for priority vector values (0.46). However, the coefficient of variation (44%) showed that the experts had different opinions, which ranged from 0.10 to 0.71 'Figure 3'.



Figure 3. Expert ratings of population interest criteria. *Source: authors' construction.* 

The next most important criterion was the reduction of poverty (especially in large families and single-parent families). This was evidenced by the arithmetic mean of priority vector values (0.33). The experts considered an increase in the number of children in the family to

be a less important criterion (0.21). However, the experts differed in their ratings as well. It should be noted that several experts emphasised that enhancing social security for the family could also affect an increase in the number of children in the family. The experts also noted that it was essential to reduce poverty in single-parent families because such families, like families with many children, were more exposed to the risk of poverty. After summarising the expert opinions on criteria for local government interests, it could be concluded that an increase in the number of residents was rated the highest 'Figure 4'.



Figure 4. Expert ratings of local government interest criteria.

Source: authors' construction.

The experts' ratings of the criteria: social burden reduction and socio-economic development were similar. The experts noted that an increase in the number of residents in municipalities was important for fostering socio-economic development. This would also promote economic activity; thereby contributing to employment as well as access to education, and the impact of these factors would decrease emigration. After summarising the expert opinions on the national interest criteria, it could be concluded that an increase in the level of financial well-being in the country was rated the highest. This was evidenced by the arithmetic mean of priority vector values (0.50). However, the minimum value of the priority vector was 0.28 and the maximum was 0.66. The coefficient of variation (27%) indicated small differences in expert opinions and a low dispersion around the mean 'Figure 5'.



Figure 5. Expert ratings of national interest criteria. *Source: authors' construction.* 

According to the experts, the next most important

criterion in the national interest group was an increase in the birth rate. This was evidenced by the arithmetic mean of priority vector values (0.37). The supply of labour in the future was less important (0.13). It should be noted that the experts had more similar opinions on the supply of labour in the future, and the coefficient of variation (0.21%) indicated it. However, the largest difference in expert opinions on national interests was for the criterion of increasing the birth rate (coefficient of variation was 38%). The experts emphasised that if the level of financial well-being in the whole country increased, the birth rate would increase and consequently the labour force would be available in the future.

At the end of the hierarchy analysis, the main scenario for increasing social protection for families with children was identified based on all the nine criteria. The experts identified Scenario 3 as the most optimal one: replacing tax relief on children with a larger family benefit (average value of the global eigenvector was 0.36). The experts differed the least on the choice of this scenario, as evidenced by the coefficient of variation of 35% 'Figure 6'.





Source: authors' construction.

Compared with the rest of the experts, two of the experts who represented population interests preferred a different scenario. Based on one expert's rating, Scenario 1 – increasing the minimum monthly wage and salary – was identified as the most optimal one. The expert justified the choice of Scenario 1 by the fact that an increase in the minimum monthly wage and salary lead to higher social insurance benefits (maternity, paternity, sickness) as well as guarantees higher income in the family budget, especially in families where both parents earn the minimum wage or salary. However, the expert who gave priority to Scenario 4 - decreasing the shadow economy - noted that the most important measure for decreasing the shadow economy was the elimination of 'envelope wages', as this would increase tax revenue paid to the special government budget (social insurance) and provide greater social guarantees for families with children. The experts' ratings of Scenarios 1 and 4 were similar (average values of the global eigenvector were 0.26 and 0.24, respectively), while Scenario 1 -

increasing the minimum monthly wage and salary slightly prevailed. The rationale for this was that the increase of the minimum wage increases household incomes and reduces family poverty, and this can also contribute to the increase of wages at other wage levels. Scenario 3 - replacing PIT relief on children with a larger family benefit - was also preferred based on population interest criteria. The ratings of the population interests also determined the choice of a scenario for enhancing social protection for families with children in Latvia because the priority vector values were the highest for the population interests. The mean values for the other scenarios were also in the same order as the respective global eigenvectors. The coefficients of variation showed that the expert opinions differed in the choice of scenarios (between 44 and 52%). The experts' ratings of criteria for municipal interests and national interests were very similar and had small values, as indicated by the average values of priority vectors calculated for all the scenarios. For the experts, Scenario 2 – increasing the PIT relief on children - was the least important; moreover, the expert opinions had a relatively low dispersion (37%), which indicated relatively similar opinions in their decision-making. However, one of the experts noted that the PIT relief for a dependent person was the relief of a social nature, which aimed to reduce the labour tax burden for those working with dependent persons, and it was also one of the instruments that promoted the legal employment of parents. The result obtained was expected because choosing Scenario 3 as the main scenario for enhancing social protection for families with children meant that Scenario 2 lost its relevance and was no longer possible to implement.

It should be noted that Lithuania has such an experience, it no longer applies a relief for dependent children from 2019; instead, the family benefit was increased.

Such a decision was made because low-wage recipients could not fully use this kind of support to the maximum extent (Lithuania introduces a ..., 2019). In this way, the risk of poverty in low-income families was reduced. If considering a possibility of replacing the PIT relief for children with a larger family benefit, it should be considered that the PIT relief is applied until the child is 24 years old and if s/he is obtaining education, while the family benefit is paid only until the child is 20 years old, and only for those who are obtaining general or professional education. If replacing the PIT relief with a benefit, it is recommended that the benefit is paid until the child is 24 years old, provided that s/he is not only acquiring general or professional education but also university education.

# Conclusions

- 1. Rating the scenarios of social protection for families with children in Latvia, the experts gave the highest ratings to population interests (families with children) because enhancing social protection would have the most significant impact on families with children. As regards the criteria for population interests, the experts rated the enhancement of social security for the family the highest, while the criterion an increase in the number of children in the family was rated as less important, noting that enhancing social protection would also contribute to an increase in the number of children in families.
- 2. Four scenarios were designed for enhancing social protection for families with children in Latvia. The experts recognised the scenario of replacing the PIT relief on children with a larger family benefit as the priority to provide fairer support also for those families with children whose incomes were low. The experts acknowledged that increasing the minimum wage and salary and decreasing the shadow economy would also increase social protection for families with children.

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# SUSTAINABLE MARKETING: CHALLENGES AND OPPORTUNITIES IN CONTEXT OF CONSUMER BEHAVIOUR

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#### Abstract

The society has changed its habits, and public demand requires a more extensive offer of environmentally friendly goods and services on the market, including more products of plant origin. New plant-based products continuously appear on the market. As competition in the segment of plant-based beverages intensifies, brands are forced into differentiating their products by including elements of sustainable marketing in their marketing materials to induce consumers into making purchase decisions and purchases. This study aims to find out which sustainable marketing elements contribute to consumer decisions to purchase and consume plant-based beverages. The article presents the results and trends based on the 1<sup>st</sup> stage of the study – a pilot survey and structured in-depth expert interviews. The pilot survey identified the key sustainable marketing at point of sale indicating price discounts; healthy product composition and raw materials; convenient in-store placement, price discounts and natural raw materials, etc. Based on the results of the pilot survey, there were changes made in the consumer questionnaire, and the 2<sup>nd</sup> stage of the study – a survey of the Latvian population to find out the complex factors affecting consumer buying decisions – was launched in February 2024.

Key words: consumer behaviour, consumer decision making, food consumption, food value chain, sustainable marketing, sustainable development.

#### Introduction

The growing public interest in various matters related to food healthiness and sustainability increasingly prompts producers, food processors and traders to respond to the developments. For instance, a growing number of milk processors and traders, fruit and vegetable producers, etc. partner with biologically certified farmers to create separate biological product sub-brands. Sustainability is on the agenda of almost every business. The interaction of the food system players in the food value chain – from the delivery of raw materials and the production of grain, livestock, fish and other agricultural products to transportation, processing, retail, wholesale, and food preparation, selling and ultimately consumption and disposal - can promote sustainable management. A key role in the overall food system value chain is also played by consumers who create demand. Specifically, demand for more sustainable products rises due to awareness of climate and environmental changes, retailers' marketing communication activities, information at retail selling points or on product packaging, etc. Moreover, an increasing share of population strives to be sustainable in their actions and willingly opt for plant-based products as well as products made by companies that implement sustainable development initiatives and abide by the principles of sustainability. However, the high price of plant-based or ecological products is often an obstacle to buying these products (Gómez & Lee, 2023; Bormane, 2018, 2021). Furthermore, consumers lack understanding of sustainability, and public awareness needs to be raised as to high-quality products and the added value environment-saving production processes, recyclable packaging, etc. (European Commission, 2023). In order to educate and advise consumers on sustainable products and the impact of their consumption, sustainable marketing needs to be used. Unlike conventional marketing which mainly focuses on promoting products and services to make profit, sustainable marketing also highlights the environmental, social and economic aspects (Belz & Peattie, 2012; Martin & Schouten, 2014; Antonetti & Maklan, 2014; Bormane 2021; Sharma, Aswal, & Paul, 2023; Bormane *et. al.*, 2023; Yadav, Gupta, & Nair, 2024).

For the purposes of this study, sustainable marketing means a strategic approach of marketing aimed towards promoting environmentally friendly and socially responsible products and services whilst highlighting the environmental, social and economic aspects and attaching great importance to building and maintaining relationship with consumers and the social, economic, natural and legal environment. Previous research has identified product packaging, information availability to consumers and loyalty programs, availability of scientific research results, affordability and product functional characteristics as the key factors affecting purchase decisions in the food product segment in Latvia (Šķiltere & Bormane, 2018). This study aims to find out which sustainable marketing elements contribute to consumer decisions to purchase end consume plant-based beverages. The article presents the results and trends based on the 1st stage of the study - a pilot survey and structured indepth expert interviews.

The article deals with the UN Sustainable Development Goals, especially – SDG 12.

#### Materials and Methods

The study takes place in multiple stages: the 1<sup>st</sup> stage identifies the sustainable marketing elements and their theoretical impact on consumer behaviour using the monographic method; the impact of sustainable marketing elements on consumer buying decisions is explored based on a pilot survey designed to find out which sustainable marketing elements contribute to consumer decisions to purchase and consume plantbased beverages; structured in-depth expert interviews are conducted. In the  $2^{nd}$  stage, based on the results of the pilot survey, there are changes made in the consumer questionnaire, the target audience for the further study is determined (people aged up to 50), and a survey of the Latvian population was launched in February 2024 to identify the complex factors affecting consumer buying decisions and to find out whether there are differences in consumer decisions to purchase and consume plant-based beverages across respondent groups – by age, sex, education, income and their choice of diet.

This article presents the results and trends based on the  $1^{st}$  stage of the study – a pilot survey and structured in-depth expert interviews.

Survey results are processed in Microsoft Excel by using crosstab analysis to compare relationships between respondent groups and sustainable marketing elements that might impact decision of purchase. To evaluate results descriptive analysis, arithmetic mean, frequency and mode are used to shed a light about key sustainable marketing elements and how they are distributed across the population of interest.

Sustainable marketing is the creation of the utmost customer value by integrating environmental and social considerations in the marketing process. This includes the development and advertising of products and services that meet customer needs whilst mitigating the adverse impact on the environment and society. Sustainable marketing has two main goals in terms of environmental and social sustainability. Firstly, sustainable marketing means marketing in a sustainable way - so that all marketing processes be environmentally friendly and socially beneficial. Secondly, sustainable marketing means sustainability of marketing as a set of concepts, cultural values and practices (Belz & Peattie, 2012; Martin & Schouten, 2014). In other words – the purpose of sustainable marketing is to help build a society where striving for sustainability is a norm. For conventional marketing, the desired result is selling and ideally also building consumer loyalty, whereas for sustainable marketing, the desired result is selling a sustainable product in such a way that the consumers have knowledge, motivation and resources to use and recycle the product in a sustainable way. Sustainable consumption can manifest itself as consumption planning to avoid impulse purchases and buying in excess, appropriate packaging sorting and recycling, etc. It is therefore a duty of businesses to educate the society on matters of sustainability in order to take care of the environment together, as the sustainability efforts of businesses will not attain the desired result if consumer behaviour and habits do not change as well (Antonetti & Maklan, 2014; Braslina et al., 2020; Casno & Sloka, 2023).

In the food supply chain, especially the selling stage, companies often see no need to invest in integrating principles of sustainability in their business. The reason in most cases is insufficient knowledge, awareness or motivation (Pislaru, Herghiligiu, & Robu, 2019).

Traders need to realise that the consumption way of

thinking promoted by conventional marketing is the main driver of adverse environmental impact. With companies increasingly offering products and services in a more sustainable way, it becomes possible to also make sure that consumers recognise and accept (by voting via their purchase) their sustainability initiatives and values aimed towards promoting sustainable consumption and maximising their strategic business advantages (White, Habib, & Hardisty, 2019). Moreover, the implementation of sustainable and environmentally friendly processes at a company results in non-financial performances that yield savings and economic benefits (Wijaya & Said, 2024).

According to previous research in this field, the growing demand for sustainable products has prompted companies to include sustainability elements in their marketing activities. For instance, statements, certificates, or other informational elements in marketing materials serve to differentiate their products from others (Annunziata, Mariani, & Vecchio, 2019). Integrating sustainability elements in marketing materials can, in turn, enhance the company's brand image and reputation by showing the company's commitment to environmental and social responsibility. Consumers increasingly tend to demand sustainable products and services, and marketing materials play a decisive role in demonstrating these attributes (Belz & Peattie, 2012). Overall, one can notice the importance of interaction with social, environmental, and economic development factors in advising and educating consumers and public on the relevance of sustainability matters. The inclusion of sustainability elements - such as stamps, certificates, eco-labels, statements, and proofs of sustainability practices - in marketing materials makes consumers not only more aware of environmental issues and environmentally friendly products, but also a key part of a sustainable practice which helps companies reach their business objectives in terms of sustainability initiatives.

When analysing literature on consumer behaviour and making purchase decisions, consumer behaviour was found to be complex process, as consumers can make informed needs-based decisions having considered various factors, or immediate buying decisions based on numerous incentives - taste, smell, design, atmosphere or economic benefits (Stankevich, 2017; Hanaysha, 2018; Egan, 2020). This study mostly focuses on the last two stages of the consumer buying decision process - purchase decision and purchase. Consumer behaviour and the buying decision process varies depending on the need, the product purchased, the motivation of purchase and use, the personal values, and the expectations of product use. It is important to use appropriate marketing activities and communication channels at each stage. Based on the theoretical aspects presented in scientific literature, one can conclude that it is the purchase decision and purchase stages at which the sustainability goals of companies and brands are attained, as the consumer
has made the choice and purchased a sustainable product (Schiffman & Kanuk, 2009; Praude & Bormane, 2012; Martin & Schouten, 2014; Kotler & Keller, 2015; Šķiltere & Bormane, 2018; Qazzafi, 2019; Egan, 2020).

The analysis of scientific literature identified seven conditions for raising consumer awareness of sustainability: 1) company impact measurement and attestation - certification and third-party audits to prove the effectiveness of sustainability initiatives by companies and brands; 2) sustainable product characteristics and composition; 3) clarity and transparency (consistency) – a clear sustainability labelling on the product packaging (certificates, stamps, statements); 4) suitability to target audience the sustainability elements highlighted in the marketing materials need to be appropriate to the target audience; 5) *sustainable* product availability; 6) sustainable product promotion; 7) long-term orientation and corporate identity - the marketing materials need to reflect the long-term commitment of the company and/or the brand to sustainability (rather than short-term superficial efforts). The said conditions are based on 59 sustainability elements which are designed for inclusion in marketing materials and used further herein to make sure of their impact on consumer purchase decisions and purchases.

#### **Results and Discussion**

In order to find out the consumers' view as to which elements of sustainable marketing contribute to making a purchase decision and purchase, a pilot survey was conducted. By territory, it targeted all working-age inhabitants of Latvia. The general population is made of employed persons residing in Latvia - 891,196 people according to the Central Statistics Bureau (Central Statistics Bureau, 2023). The representative sample for the pilot survey, with the acceptable error of 5%, is 384 respondents. 414 respondents took part in the survey (n-414, 351 or 85% were women, 63 or 15% were men, the survey period ran from 09.11.2023 till 08.12.2023). Women and men are not represented equally among respondents, but the interpretation of results factored in that most buying decisions in the family (especially when it comes to food) are made by women (Krizan et al., 2022) and such structure of respondents is therefore appropriate to the specifics of the study.

Data were collected across five respondent groups: 1) diet – vegetarian (abstains from the consumption of meat), vegan (abstains from the consumption of products derived from animals), flexitarian (periodically abstains from the consumption of products derived from animals or consumes some plant products, such as plant-based milk), omnivorous (consumes both meat and milk products) or other; 2) sex (male or female); 3) age (up to 24, 25-50, 51 and older); 4) net income per month (no regular income, up to 534 EUR, 535-1,114 EUR, 1,115 EUR and more); 5) education (primary, secondary, higher, other). Prior to the study, it was assumed that plant-based products are predominantly consumed by vegetarians, vegans and flexitarians, but the results of the pilot survey show an increasing number of plant-based product consumers among respondents who describe themselves as omnivores. This is most often the case with men (67%) and respondents aged above 51 (66%), whereas most women (54%) count themselves under the category of flexitarians, vegans or vegetarians. Many respondents aged 25 to 51, too, count themselves under these categories (49%). Interestingly, it is most often respondents with secondary education (59%) who count themselves as flexitarians, vegans or vegetarians, followed by those with higher (incl. incomplete higher) education (49%). Such result stems from generational differences in understanding – younger respondents (with secondary education) have grown up in an informational space where sustainability issues are present, so these respondents tend to opt for a more sustainable diet more often.

For analysing the results of the pilot survey and assessing the impact of the 59 sustainable marketing elements on the purchase of plant-based beverages, the arithmetic mean rating was used 'Figure 1'.





Source: arithmetic mean respondent rating, scale of ratings: (-2) unimportant; (-1) rather unimportant; (0) neutral; (1) rather important; (2) important).

In all demographic groups of respondents, *product characteristics and composition* were rated as the most important conditions when it comes to purchasing sustainable products, while *long-term orientation* and *corporate identity* were rated as the least important.

Overall, respondents aged up to 24 and those counting themselves as vegans tend to rate the impact of sustainable marketing elements on the purchase of sustainable products as rather high, which suggests that these respondent groups are more sensitive to the different marketing activities. Men and respondents aged over 51, in turn, rate this impact lower. Older respondents tend to rate the impact of sustainable marketing elements on purchase decisions as neutral and pay less attention to sustainable marketing activities when shopping.

The results of the pilot survey show a general trend that the use of sustainable marketing elements in marketing materials contribute to making purchase decisions and purchases. For instance, consumers appreciate convenience, physical availability, and convenient packaging.

According to the results, consumers attach great importance to price discounts, product composition, raw materials, environmental and animal impact, which play a major role in context of purchasing sustainable products. Product packaging colour, floor labels at points of sale, authentic sustainability message, and participation in sustainability conferences, in turn, have been rated as the least important sustainable marketing elements for the promotion of buying. Surprisingly, lotteries - widely used as sales promotion activities have been rated negatively. It might be because of the extensive use that consumers no longer find such promotion mechanism appealing. Outdoor advertisement showing product features and positive environmental impact, too, has been rated as unimportant or neutral, probably because consumers have no time to delve into the content of the advertisement to fully perceive the message.

The results also show a substantial difference in the rating of sustainable marketing elements between women and men. For instance, price discounts and convenient and intuitive in-store placement are the most important sustainable marketing activities affecting purchase decisions for men. Women, in turn, find healthy product composition important. Overall, one can conclude that men place greater importance on rational and functional product values.

Rational elements (ease of use and financial benefit) draw much attention regardless of age group. Meanwhile, the younger the consumer, the more attention is devoted to sustainable marketing elements, which makes the consumer easier to influence. For those aged between 25 and 50, the importance of sustainable marketing elements in making purchase decisions is lower, but relatively important is product availability, convenience, healthy composition and raw materials, with price discounts rated as less important. The age group of 51 and above shows the most surprising results – contrary to expectations that older respondents might prioritise price discounts and other promotional activities, this group has rated sustainable marketing elements pertaining to natural, biological and ecological raw materials as the most important, and price discounts are not even near the top of the list. This suggests that older respondents pay more attention to their health, purchases are planned in

advance, and decisions are thoroughly considered rather than impulsive.

Different dietary groups rate sustainable marketing elements differently. Omnivores and flexitarians pay more attention to functional elements pertaining to convenience and availability, whilst also considering healthy product composition and price discounts. Vegetarians, too, appreciate product availability at supermarkets but even more healthy product composition and raw materials with no adverse animal impact. Price discounts are not ranked among 5 most important elements for buying sustainable products. Vegans, on the contrary, attach much greater importance to raw materials with no adverse animal and environmental impact. They also appreciate easily sortable product packaging, and they, too, have not ranked price discounts among the most important elements, which suggests that this group pays much more attention to sustainability matters and the use of sustainable marketing elements can affect their purchase decisions and purchases.

Comparing respondents by income, it is evident that all groups rate product availability as the most important element. Naturally, respondents with no regular income and low to average income also rate price discounts as important, whereas those with income above 1,115 EUR per month and those who prefer not to specify their income level have not ranked price discounts among the most important elements. Respondents with higher income rate availability, convenience and healthiness as more important, with price discounts and campaigns ranked lower. Respondents with average or low income and without regular income have, in turn, rated price discounts as more important. Respondents without regular income appear to be more oriented towards sustainable action - the only group to rate the environmental impact of raw materials so high, while respondents with average and high income and those who have not specified their income level pay more attention to healthy product composition.

Overall, respondents see rational elements, such as product availability and convenient and easily sortable packaging, as important for promoting the purchase of sustainable products, as these elements allow one to buy sustainable products and become more sustainable oneself without much effort. Consumers have rated price discounts as important, which is understandable in the current economic circumstances, but healthy product composition and raw materials with no adverse animal and environmental impact are rated high, too. These are therefore the sustainable marketing elements that one should focus on and companies (brands) should implement in their marketing materials and activities. One can observe a trend that price discounts are currently important to consumers in Latvia. The older the respondents, the more sensitive to price changes they become and the more importance they attach to product packaging and ease of use.

# SUSTAINABLE MARKETING: CHALLENGES AND OPPORTUNITIES IN CONTEXT OF CONSUMER BEHAVIOUR

Consumers sometimes act inconsistently with their views expressed in surveys – in the case of sustainable management, purchase decisions may differ from the theoretical and practical knowledge in this field. After summarising the results of the pilot survey and identifying the trends of consumer behaviour, structured in-depth expert interviews (n-10) were conducted to find out the opinions of experienced marketing and sustainability experts on the use of sustainable marketing elements in influencing consumer purchase decisions and promoting purchases. The experts selected were industry professionals with at least 10 years of experience. The structured in-depth expert interviews period ran from 19.12.2023 till 21.01.2024.

When asked about consumer awareness and understanding of sustainability matters, the experts were unanimous that understanding of sustainability matters is improving overall but is still low among Latvian consumers compared to other European countries (European Commission, 2023). Importantly, it greatly varies among consumer groups - for instance, younger consumers, or the so-called Generation Z, are certainly more knowledgeable and themselves actively pursue sustainable actions on a daily basis, whereas older generations have much less understanding and knowledge on sustainability matters. Part of the society see sustainability as a global problem that does not concern them directly or perceive it as a problem imposed by European Union directives. The experts also stress that the state should engage more in informing the public and building a deeper understanding of sustainability matters because currently this lies on the shoulders of businesses and non-governmental organisations.

The experts were asked to rank by importance the conditions for building understanding of sustainability to promote decisions of buying sustainable products (especially plant-based products) 'Figure 2'.

The experts picked *sustainable product availability* as the most important one, referring in comments to both physical in-store presence and affordability. It was followed by *suitability to target audience* – according to the experts, it is very important to educate and tell consumers what the brand does and why sustainable development in general is important. Furthermore, this information needs to be delivered in an appropriate and gripping way.

Also, rated as very important were *sustainable product characteristics and composition*, which is actually an essential precondition for talking of including sustainable elements in marketing communication at all. *Sustainable product promotion* and *clarity and transparency* have been rated as important. Consumers need clear and unambiguous elements that prove the sustainability of the product and brand, while promotional activities serve to both introduce consumers to the story of the brand and raise awareness of sustainable development in general.

The experts rated *long-term orientation* and *corporate* 

*identity* as the least important conditions – not because they are unimportant as such, but because they do not directly contribute to making purchase decisions and purchases. The experts stress that brands certainly need to work with these conditions but also keep in mind that they will require long-term activities that do not yield immediate purchases.



Figure 2. Conditions for the promotion of purchase of sustainable products in order of importance, 2023,

n=10.

*Source: arithmetic mean, expert rating, evaluation scale: (7) most important; (1) least important.* 

As concerns sustainable marketing elements and their impact on consumer decisions and sustainable product purchases, the experts mentioned advertising at point of sale (posters, stands and other POS materials) indicating price discounts as well as product availability at supermarkets as facilitating marketing activities. It was stressed in the interviews that normally price discounts should not be a decisive factor in purchasing sustainable products but the current economic situation in Latvia gives price a key role in product selection.

Overall, the main differences between the consumer views in the pilot survey and the expert assessment of the use of sustainable marketing elements for the promotion of purchase decisions and purchases are that the experts rated advertising materials at points of sale indicating price discounts as very important, while the consumers only rated these elements as rather important. The latter stems from the consumers' unwillingness to recognise that their buying decision may be influenced by advertising materials at points of sale. Sustainability message in the form of authentic story-telling, in turn, has been rated as important by the experts but neutral with a negative trend by the consumers. According to the experts, it is story-telling that helps build brand awareness, understanding of sustainability matters, and also brand loyalty. There is also a substantial difference in ratings for outdoor advertisement showing product features – important according to the experts and neutral according to the consumers. Here one can give a similar explanation that consumers are not fully aware of the factors and elements that influence and incite them towards making purchases.

The results of the consumer pilot survey and the expert interviews on the conditions for promoting consumer understanding of sustainability and sustainable marketing elements to promote consumer purchase decisions and purchases are summarised in Table 1.

Table 1

Sus	stainable marketing elements which c	ontribute to consumer	purchase decisions and j	purchases

understanding of sustainability	purchase decisions and purchases
Product	availability at food supermarkets and online stores,
Sustainable product availability Conv	enient and intuitive in-store placement, on-shelf
concentr	ration – at least 3 products of the same brand placed
	together.
Advertis	ing stands and posters at points of sale, mass media
Sustainable product promotion advertising	ng indicating price discounts, price discounts, tasting
	at points of sale.
Health	hy product composition, raw materials or natural,
biologica	al, ecological or local origin, without food additives,
sustainable product characteristics raw ma	aterials with no adverse animal and environmental
<i>ana composition</i> impact, r	backaging is easy to use, made of recycled materials,
	easy to sort, recycle or reuse.
Clarity and transparency An	ecolabel or biolabel on the product packaging
Suitability for target and image The susta	ainability message stresses benefit to the consumer's
Sunadning for largel audience	health.
Sustainable product availabilityConv concentreSustainable product promotionAdvertise advertising advertising advertising advertising advertising advertising the advertising the advertising advertising the advertising the adver	enient and intuitive in-store placement, o ration – at least 3 products of the same bra- together. ing stands and posters at points of sale, n ing indicating price discounts, price discou- at points of sale. hy product composition, raw materials or al, ecological or local origin, without food aterials with no adverse animal and enviro backaging is easy to use, made of recycled easy to sort, recycle or reuse. ecolabel or biolabel on the product packa inability message stresses benefit to the health.

Source: Author's calculations based on the results of the pilot survey\* and structured expert interviews\*\*. Scale: \*(-2) to (2) for consumer ratings where (-2) important; (-1) rather unimportant; (0) neutral; (1) rather important; (2) important; \*\*(1) to (7) for expert ratings where (1) – unimportant; (7) – important.

#### Conclusions

- 1. There is a trend that consumer purchase decisions and purchases are contributed to in particular by such sustainable marketing elements as: product availability at food supermarkets; advertising stands and posters at points of sale indicating price discounts; healthy product composition; convenient and intuitive in-store placement; price discounts; natural raw materials, without food additives; convenient packaging (volume, use); easily sortable packaging; raw materials with no adverse animal impact, etc.
- 2. By including sustainable marketing elements such as stamps, certificates, ecolabels as well as statements and proofs of sustainability practices used in marketing materials, companies cannot only improve consumer understanding of sustainability, knowledge on environmental issues and environmentally friendly products, but also engage consumers in the promotion of sustainable practices.
- 3. Both rational elements (such as product availability, convenient packaging, price discounts and healthy product composition) and social elements (raw materials with no adverse environmental impact) are rated as important for the promotion of sustainable products. Stimulating sustainable marketing activities for drawing attention may be price discounts (especially for older consumers), but the

price becomes less important as the consumers' income level increases, and then it becomes more about the functional benefits of the product. This leads to a conclusion that consumers with a higher income level more consciously choose to consume sustainable products and purchase them based on origin, ingredients, packaging, ease of use, etc.

- 4. Overall, one can conclude that it is important to address specifically women, the younger audience, and the vegan audience through sustainable marketing elements, as these categories place greater importance on the use of sustainable marketing elements in promoting purchases.
- 5. The results of the pilot survey and expert interviews have been used for the 2<sup>nd</sup> stage of the study launched in February 2024 to find out the views of the Latvian working-age population on the complex factors affecting the purchase of sustainable food products and establish whether there are differences in consumer decisions to purchase and consume plant-based beverages across different respondent groups.

The results of the study will be of use to businesses for promoting food products and raising discussions on the need to develop social campaigns highlighting sustainability issues and informing the public, and to other researchers for in-depth studies.

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## THE ROLE OF SUSTAINABILITY CRITERIA IN CONTROLLING THE QUALITY OF AGRITOURISM SERVICES IN UZBEKISTAN

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#### Abstract

The global character of sustainable development has made agritourism a popular phenomenon in both developed and developing countries, as it is advantageous from the standpoint of local economic and social development. Sustainability criteria play a vital role in controlling the quality of agritourist services of leader countries in agritourism. However, the development of agritourism in Uzbekistan has very different characteristics and development levels compared to other countries, especially countries in Western Europe. This article explores the integration of sustainability principles within the quality of agritourism services in Uzbekistan. As Uzbekistan's agritourism industry continues to grow, the importance of sustainability criteria in ensuring the quality of agritourism services in Uzbekistan. The research findings indicate that there is a growing interest in agritourism in Uzbekistan. However, there is a need to improve the quality and sustainability of agritourism services in order to meet the expectations of tourists. This, in turn, enhances the overall visitor experience and contributes to the long-term sustainability of the industry. This article, relying on quantitative method, reveals the assessment of quality of agritourism services in Uzbekistan, the article emphasizes the nation's strategic initiatives to promote sustainability point of view. In the context of Uzbekistan, the article emphasizes the nation's strategic initiatives to promote sustainable resource management, water efficiency, conservation, and environmental preservation in its agricultural and agritourism sectors ensuring the delivery of high-quality services and products while contributing to environmental preservation.

Key words: agritourism, quality label, sustainability, rural development.

#### Introduction

The size of the world market for agritourism was US\$ 65.6 billion in 2023. According to IMARC Group's projections, the market would increase at a pace of 11.45% from 2024 to 2032 and reach a value of US\$ 176.6 billion. Air pollution in cities (Zhang et al., 2015), GMOs in food (Azadi, Taube, & Taheri, 2017), as well as other global problems cause an increase in the number of tourists in agritourism places. People are actively choosing both inbound and outbound agritourism because of the clean environment, fresh food, leisure activities, and other health benefits associated with agritourism. The ability for visitors to select fresh fruits straight from farms at the different agritourism-related on-farm farmer's markets draws a lot of people to the industry (Mahaliyanaarachchi, 2015).

Sustainability criteria in agritourism: The problem of utilizing resources sustainably and efficiently in the new century is what is driving improved changes in the ways that we create, consume, and live. This proves to be an increasingly significant obstacle, particularly for companies in the agriculture industry (Whitfield, Challinor, & Rees, 2018). The attempt to meet the growing global demand for food as a result of population growth may be the solution to this problem. This can be done by using agricultural practices and techniques that allow for increased farm productivity and the provision of environmental services without depleting resources while also controlling wastes and harmful environmental externalities. By investigating the topic, study shows that one of the key benefits of agritourism, which is a subset of rural tourism, is the enhancement of food and gourmet options, which boosts the region's economic and social well-being (Mackay, Nelson, & Perkins, 2019). Agritourism also

gives local farmers the opportunity to earn additional revenue (Bhatta, Itagaki, & Ohe, 2019).

In the table below, the matrix of sustainable agritourism is proposed by Ammirato. In this matrix, the extent to which agritourism can affect the economic, social and natural environment on micro and macro scales, based on bibliographic information from the works of various scientists, is shown (Table 1). The matrix of sustainable agritourism (Ammirato *et al.*, 2020) highlights the relationship between rural society and sustainable economy (Roberts & Tribe, 2008; Barbieri, 2013; Naido & Sharpley, 2016), environmental sustainability (Barbieri, 2013; Pratt, Suntikul, & Dorji, 2018; DeRosa, McElwee, & Smith, 2019), social sustainability in agritourism (Choi & Sirakaya, 2006; Roberts & Tribe, 2008; Barbieri, 2013).

The economic, environmental and social dimensions of the matrix assess the economic, environmental and social benefits of agritourism for both the local community and the agritourism business itself.

Businesses can use the matrix to identify areas where they can improve their sustainability practices. The matrix can also be used by governments and other stakeholders to develop policies and programs that support sustainable agritourism development. Overall, the matrix of sustainable agritourism is a useful tool for promoting sustainable agritourism development.

*Quality issues in agritourism:* Today's travelers are more knowledgeable and concerned about what they eat, where the food comes from, and how it is produced. In fact, food is one of the major reasons that they travel, and agriculture provides a real sense of place. Agritourism has emerged as a niche market that combines agriculture and tourism. Increasingly, both farm hosts and guests are becoming better informed in the way they can adjust their choices and

preferences to better meet each other's expectations, emphasize quality standards in various aspects of the provision. Quality in agritourism plays a crucial role in deriving volume and value of the business. A number of different scholars have focused on the importance of quality services provided at accommodation facilities and catering, the role of the staff and the activities offered, and linkages with quality local products.

Table 1

Economic:		
Macro level:	Micro level:	
Stimulus for other local activities, boosting local	Alternative source income for the farmer;	
economies;	Business diversification;	
Infrastructural investments.	Distribution channel for farm products;	
	Developing new markets niches.	
Environmental:		
Macro level:	Micro level:	
Natural resources maintenance;	Responsible use of raw materials and natural	
Biodiversity and environmental protection.	resources;	
	Waste reduction.	
Social	1:	
Macro level:	Micro level:	
Recovery of roots, folklore, and traditions;	Provide alternative job opportunities to family	
Educate visitors toward agriculture and the rural world.	members; Enabler of emancipation of women.	

The matrix of sustainable agritourism

Currently, there are two types of quality labels for agritourism: one is related to the food quality, while the other is related to the sustainability of service quality (Peri, Rizzo, & Traverso, 2010).

The EU Ecolabel for Tourism Services, to assesses the environmental performance of the agritourism lodging business.

In addition to the more sophisticated industry requirements pertaining to the evaluation of food quality (which encompass the food chain and the traceability of the company), there are the PDO, PGI, TSG, and DOC brands. In order to assess the environmental strain that agricultural operations (and the food chain, among others) impose, the Life Cycle Assessment (ISO, 2006) technique is used.

The growing global demand and motivation for agrotourism forces world researchers to pay attention to the sustainable development of this field in their countries. Relying on the relevance of the above topic, this research is being carried out in Uzbekistan in order to study the importance of organizing the quality of services on the basis of sustainability criteria in agrotourism. The **research question** is as follows:

How do sustainability criteria contribute to controlling the quality of agritourism services in Uzbekistan?

**Aim:** To investigate the role of sustainability criteria in enhancing the quality of agritourism services in Uzbekistan.

#### **Objectives:**

- 1. To review the scientific literature on agritourism and sustainability.
- 2. To conduct a survey to determine the quality of agritourism services in terms of sustainability in Uzbekistan.
- 3. To analyze the data from the survey to:
  - Describe the characteristics of local agritourism participants in Uzbekistan;

- Determine the importance of sustainability criteria to local travelers when choosing an agritourism services;
- Assess the quality of agritourism services in Uzbekistan.
- 4. To make recommendations for improving the quality and sustainability of agritourism services in Uzbekistan.

Background of tourism in Uzbekistan: After gaining independence, Uzbekistan began to pay attention to other sectors along with the agricultural sector, and the tourism sector also became a growing trend among them (Rakhmanov & Ibragimov, 2019). The government of Uzbekistan, along with all other economic sectors, has endeavoured to provide an environment that is very favourable and supportive of the tourism industry's longterm growth, given the country's high potential in this sector as a competitiveness of the destination (Ibragimov & Khamidov, 2023). The government has also been paying increasing attention to agritourism in rural areas in recent years. For instance, Uzbekistan's Ministry of Agriculture and Ministry of Tourism and Sports have been working closely together to create agritourism initiatives. Consequently, Uzbekistan has experienced a significant increase in the number of international tourists during the previous five years. According to the World bank data, in 2023, the number of international tourists amounted to 6.6 million visitors to Uzbekistan, see 'Figure 1'.

Scholars in the field acknowledge the significance of agritourism in the sustainable development of rural regions and in the plan to improve the standard of living for the rural people (Mahaliyanaarachchi, 2015). Increasing additional revenue through tourist-related activities is the goal of the agricultural-based tourism, Sustainable Development Strategy, which takes into account harvesting, agriculture, the environment, engaging in farming practices, and leisure (Tew & Barbieri, 2012).



■ Number of tourists in million(s)

Figure 1. Number of foreign tourists in Uzbekistan, almost all of these tourists visited Uzbekistan for the purpose of leisure (Sayfullayeva, 2022).

These kinds of social activities are predicated on rural farms engaging in agricultural operations, which fosters the environment that is conducive to the long-term growth of agritourism. The global character of sustainable development has made agritourism a popular phenomenon in both developed and developing countries, as it is advantageous from the standpoint of local economic and social development. It also encourages environmentally friendly agriculture and development within rural areas by creating extra off-farm employment opportunities and encouraging diversified production. However, the development of agritourism in Uzbekistan has very different characteristics and development levels compared to other countries, especially countries in Western Europe.

#### **Materials and Methods**

The research on the role of agritourism in Uzbekistan was conducted in several stages:

Firstly, a review of scientific literature was conducted to investigate the importance of the quality of agritourism services in terms of sustainability. The literature review covered a range of topics, including:

- The growing market characteristics of agritourism,
- The benefits of agritourism for rural communities,
- The role quality ensuring sustainability in agritourism services.

Secondly, analysis of national statistical data was carried out.

Key indicators of the agriculture and tourism sectors in Uzbekistan were analyzed using data from various national statistical portals. The data was used to:

• Assess the current state of the agritourism industry in Uzbekistan,

• Determine the potential for growth in the industry. Followingly, a survey was conducted to determine the quality of agritourism services in terms of sustainability. The survey was conducted online using Google Forms and the sample size of 312 respondents from different regions of Uzbekistan participated. The survey consisted of five sections and was designed to collect data on the following topics:

- The demographics of respondents participating in the survey,
- Agritourism experience- the types of agritourism services that tourists participate in,
- The importance of sustainability criteria to tourists when choosing an agritourism service
- Quality of agritourism services,
- The willingness of tourists to pay for sustainable agritourism services.

The data from the survey was analyzed using a statistical technique like descriptive statistics.

The data analysis was used to:

- Describe the characteristics of agritourism tourists in Uzbekistan,
- Identify the most popular types of agritourism services,
- Determine the importance of sustainability criteria to local tourism participants,
- Assess the quality of agritourism services in Uzbekistan,
- Determine the willingness of tourists to pay for sustainable agritourism services.

## **Results and Discussion**

*Findings on agritourism potential in Uzbekistan:* A significant portion of Uzbekistan's GDP - about 25% - comes from the agricultural sector, which also employs over 26% of the labour force. Beginning on June 1, 2022, the state began buying and selling grain at market pricing in order to further liberalize the industry and account for a sharp increase in wheat prices worldwide. In 2022, Uzbekistan's foreign revenues from agricultural exports accounted for around 8.4% of total earnings. Through intense development initiatives, the application of cutting-edge scientific discoveries, digitization, and the adoption of new technology, the government wants to quadruple farmers' income and assure a minimum 5% annual increase in agriculture in 2022–2026.

A major goal of continuing agriculture reforms is to support the development of vertically integrated clusters, of which 633 had been registered as of 2022, and a cooperative system that offers a whole production chain 'from the field to consumer' in order to increase productivity. It can be seen that the number of agricultural products and services across regions has only been growing over the years, see 'Figure 2'. In order to support this growth, the government is creating a number of incentives. A total of \$600 million in grants and loans will be drawn toward the adoption of contemporary agricultural technology, land fertility enhancement, and digital agriculture. All areas will see the creation of Agricultural Knowledge and Innovation Centres between 2022 and 2026, offering more than 100 different agricultural services under one roof, including crucial services like enhancing soil quality, preventing plant

diseases, and selecting. 90% of the water resources in Uzbekistan are used for the agricultural sector. The state intends to increase efficiency and conserve the water by 2030 strategy (Republic of Uzbekistan PD, 2020). It is now funding the implementation of water-saving technology. According to the World Bank, Uzbekistan is now among the least productive 20 nations in the world, producing only \$0.6 per cubic meter of water, compared to the average of \$15 per cubic meter worldwide. This demands new policies enforcing sustainability.



Figure 2. Volume of products and services created in agriculture (by region).

The above statistical data show that there are enough opportunities in the field of agrotourism in Uzbekistan, and the creation of services in this field is growing. However, in order to better study the situation and ensure long-term quality in this field, it was first required to study the attitude of local tourists and residents to the quality of services of agrotourism based on sustainability.

Table 2						
5	Section 1. Demographic Information					
	Category	Frequency	%			
e	18-24	135	43.3			
Ag	25-34	77	24.7			
51	35-44	49	15.7			
$\smile$	45 and over	51	16.3			
	Total	312	100			
er	Male	143	46.7			
Q2 Inde	Female	163	53.3			
U U	Total	306	100			
	Tourism	19	6.1			
ion	Teacher	36	11.7			
pat	Agriculture	22	7.1			
noc	Student	92	29.8			
ŏ	Retire	29	9.4			
<b>0</b> 3	Other	111	35.9			
	Total	309	100			
10.	Higher	143	46.4			
24 cati	Collage	117	38			
Gdu	High school	48	15.6			
E	Total	308	100			

Therefore, the following main findings can be concluded from the results of the research:

*Section 1: Demographic Information (Table 2):* Q1, Q2: The survey respondents were primarily between the ages of 18-24 (43.3%) and 25-34 (24.7%), with a slightly higher proportion of females (53.3%) than males (46.7%).

Q3: In terms of occupation, the largest group of respondents were students (29.8%), followed by those in the 'other' category (35.9%), which includes a wide range of occupations. The next largest groups were teachers (11.7%), retirees (9.4%), and those in agriculture (7.1%).

Q4: The majority of respondents had a higher education (46.4%), while 38.0% had a college education and 15.6% had a high school education.

The survey respondents were a relatively young and diverse group in terms of age, gender, and occupation. A significant proportion of respondents were students, suggesting that the survey is much targeted towards a younger population and much younger segment seems are willing to participate in agritourism.

Section 2: Agritourism practice 'Figure 3': The majority of respondents (64.5%) have participated in at least one agritourism activity. This indicates that agritourism is a popular activity in Uzbekistan. A significant proportion of respondents (20.8%) have not participated in any agritourism activities. A small proportion of respondents (14.7%) are interested in participating in agritourism activities in the future. This indicates that there is a growing interest in agritourism in Uzbekistan in the future. The section

findings suggest that there is a growing demand for agritourism services in Uzbekistan.



Figure 3. Respondents' participation in agritourism.

*Section 3. Sustainability criteria:* Q6: With the considerable share (58.6) participants' choice was all three sustainability pillars while traveling. Q7: The significant proportion of respondents (48.2%) believe that the agritourism services they have experienced meet the sustainability criteria only partially.

Table 4						
Section 3. Sustainability Criteria						
ving en e?	Category		%			
e follow you wh 1 servic	Environmental conservation	54	17.8			
nt are th teria to itourisn	Social responsibility	34	11.2			
mportar illity cri g an agr	Economic sustainability	38	12.5			
How i stainab oosing	All	178	58.6			
Q6 sus ch	Total	304	100			
No such criterion		30	10.9			
do you n service ced meel ity criter	Partially	133	48.2			
low well ritourisr xperiene tainabili	Completely meets	113	40.9			
Q7 H the ag have e sus	Total	276	100			

This suggests that there is room for improvement in the sustainability of agritourism services in Uzbekistan. A noticeable proportion of respondents (40.9%) believe that the agritourism services they have experienced completely meet the sustainability criteria. This indicates that there are some agritourism businesses in

Uzbekistan that are implementing sustainable practices and meeting the expectations of tourists. A small proportion of respondents (10.9%) do not believe that the agritourism services they have experienced meet any of the sustainability criteria. This suggests that there are some agritourism businesses in Uzbekistan that are not implementing sustainable practices and are not meeting the expectations of tourists. This section findings suggest that local tourists are increasingly concerned about the sustainability of agritourism services.

Section 4. Quality of Agritourism Services (Table 5): Q8: The most satisfying aspect of agritourism services for respondents was food and beverages (34.4%). This encourages that agritourism businesses should focus on providing high-quality food and beverage experiences. Other aspects of agritourism services that satisfied respondents include staff friendliness and knowledge (24.3%), activities (18.8%), and accommodation (10.1%). This suggests that agritourism businesses should also focus on providing excellent customer service, offering a variety of activities, and providing comfortable accommodation.

Q9: The most recognized quality label among respondents was ISO (39.9%). This suggests that agritourism businesses should consider obtaining ISO certification in order to demonstrate their commitment to quality. Other quality labels that are recognized by respondents include UzStandart (24.1%) with a bit share of Ecolabel (18.2%) and none of them recognizable (17.8%). This means that agritourism industry needs labelling the quality policy and there is a lot to do in this field.

Q10: In the next question, the majority of respondents (61.6%) agreed that the agritourism service they participated in did not harm the environment. This suggests that agritourism businesses are generally implementing sustainable practices. However, only a small proportion of respondents (0.3%) agreed that the agritourism service they experienced was economically sustainable. This suggests that there is room for improvement in the economic sustainability of agritourism services in Uzbekistan. Similarly, only a small proportion of respondents (2.6%) agreed that the agritourism service they participated in supported and benefited the local population. This suggests that there is room for improvement in the social sustainability of agritourism services in Uzbekistan.

Q11: The majority of respondents (81.8%) want their children to participate in high-quality organized agritourism trips in the future. This suggests that most parents want their children experiencing agritourism. Q12: The majority of respondents (56.1%) were satisfied with the overall quality of their agritourism experience. This suggests that there are a number of agritourism businesses in Uzbekistan that are providing high-quality services.

Table 5

Section 4. Quality of Agritourism Services				
Q8 Which of the following	Category	Frequency	%	
aspects of agrotourism services	Accommodation	28	10.1	
satisfied you?	Food and beverages	95	34.4	

#### THE ROLE OF SUSTAINABILITY CRITERIA IN CONTROLLING THE QUALITY OF AGRITOURISM SERVICES IN UZBEKISTAN

Continuation of the Table 5

	Staff friendliness and knowledge	67	24.3
	Activities	52	18.8
	None of them	34	12.3
	Total	276	100
	ISO	121	39.9
	Ecolabel	55	18.2
Q9 Which of the following	UzStandart	73	24.1
quanty labers do you recognize?	I don't know any of them	54	17.8
	Total	276	100
	The agrotourism service I participated in did not harm the environment	186	61.6
O10 How much do you agree	The agritourism service I experienced was economically sustainable	1	0.3
with the following statements?	The agritourism service I participated in supported and benefited the local population8		2.6
	I have no idea	107	35.4
	Total	302	100
Q11 Do you want your children	Yes	248	81.8
to participate in high-quality	No	55	18.2
the future?	Total	303	100
	Good	101	33.3
	Bad	15	5
Q12 How satisfied were you	Avarage	63	20.8
agritourism experience?	Excellent	69	22.8
	No such experience	55	18.2
	Total	303	100

Section 5. Willingness to pay (Table 6): Q13: The noticeable proportion of respondents (38.6%) are willing to pay extra for agritourism services that meet high sustainability criteria suggesting that tourists are increasingly concerned about the environmental and social impact of their travel. However, a significant proportion of respondents (44.8%) are on the opinion that this might be on their future choices. This suggests that there is a need to raise awareness of the importance of sustainability in agritourism.

Q14: 69.3% of respondents think that agritourism services bearing quality labels are crucial. This implies that travellers are looking for agritourism services that are verified as being high-quality and sustainable. Nonetheless, a sizeable segment of participants (17.6%) thinks that agritourism offerings bearing quality designations are merely somewhat relevant. This implies that more people need to be made aware of how crucial quality labels are to the agritourism industry.

Table 6				
Section	n 5. Willingn	ess to Pay		
s to ism a?	Category	Frequency	%	
villing ritour neet hi criteri	Yes	118	38.6	
you v for ag that m bility	No	51	16.7	
3 Are extra vices staina	May be in the future	137	44.8	
Q1 pay ser su	Total	306	100	
n s ou?	Of course	212	69.3	
Are Aurism es with abel t to ye	Not important	40	13.1	
Q14 agrotc service quality portan	Partially	54	17.6	
in a state of the	Total	306	100	

#### Conclusions

The following can be concluded from the research results:

- 1. Based on the theoretical basis of the research at the initial stage, it was determined that there are enough opportunities for agrotourism in Uzbekistan. However, it was theoretically justified that quality management in terms of sustainability is a priority in the industry.
- 2. According to the first section of the survey, the survey respondents was a relatively young and diverse group in terms of age, gender, and occupation. It is evident that agritourism motive is higher for younger generation rather than other age profiles. Seemingly, the higher education, the greater the knowledge about agritourism.
- 3. Based on the second section of the results, agritourism practice is much common among local travelers. The majority of respondents have participated in at least one agritourism activity, indicating that agritourism is a popular activity in Uzbekistan. A significant proportion of respondents have not participated in any agritourism activities, and a small proportion of respondents are interested in participating in agritourism activities in the future, indicating

that there is a growing interest in agritourism in Uzbekistan.

- 4. Third section summarises sustainability criteria, travelers consider all three sustainability criteria (environmental conservation, social responsibility, and economic sustainability) to be important when choosing an agritourism service. This suggests that local travelers are increasingly concerned about the environmental and social impact of their travel. Agritourism businesses that are able to implement sustainable practices and meet the expectations of tourists will be more likely to attract and retain customers.
- 5. The quality of agritourism services in Uzbekistan is generally good. Respondents mostly made positive choices about food and drinks, which indicates the need to improve the rest of the services as well.
- 6. A significant proportion of respondents are willing to pay extra for agritourism services that meet high sustainability criteria. This suggests that local tourists are beginning being concerned about the environmental and social impact of their travel. Agritourism businesses can capitalize on this trend by implementing sustainable practices and obtaining quality labels.

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## IMPACT OF THE WAR ON THE EXPORT OF UKRAINIAN ORGANIC AGRICULTURAL PRODUCTS

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#### Abstract

One of the promising areas of creating a competitive market environment is the development of organic production. Under martial law, organic producers faced not only problems related to the export of organic products, but also other challenges caused by the military actions of the aggressor. The purpose of the study is to assess the impact of the war on the export of organic products by domestic agricultural enterprises. The article reveals the general state and changes in the dynamics of export of organic agricultural products by domestic organic producers; the challenges faced by producers of organic products in the conditions of martial law are presented; the impact of the war on the export of organic agricultural products by producers of the value of agricultural products exported by Ukraine for the period until 2025 was made (with the help of retrospective and statistical research methods); directions for supporting exporters of organic products for their development in the future are given. As a result of the authors' research, it should be noted that export operations of organic products will increase, which will allow to ensure the strategic goals of Ukraine regarding development in the market environment.

Key words: war, export, foreign market, organic agricultural products, market environment.

#### Introduction

Ukraine has significant potential in the field of organic production and is one of the leaders in the volume of exports of organic products. The full-scale war in Ukraine affected the ability of business entities to carry out their activities, expand exports and overcome logistical difficulties. In today's conditions, not only the growth of the export of raw materials, but also of organic products with a high added value is gaining importance.

The purpose of the study is to assess the impact of the war on the export of Ukrainian organic agricultural products and to determine the strategic guidelines for the development of organic exports.

The goals of the study are:

1. To reveal the general state and dynamics of changes in the export of organic agricultural products by domestic organic producers.

2. To present the challenges faced by producers of organic agricultural products in the conditions of military aggression.

3. To determine the impact of the war on the export of organic agricultural products by producers of organic products.

4. To make a forecast of the value of agricultural products exported by Ukraine for the period until 2025.

Organic agriculture – marketing opportunities

Responding to the International Federation of Organic Agricultural Movement (IFOAM) definition, 'Organic agriculture is a production system that supports healthy soils, ecosystems and people'. Organic agriculture is based on ecological processes, biological diversity and natural cycles, while minimizing the use of harmful pesticides that have a negative impact on the environment.

Gulieva K. within the framework of the project 'German-Ukrainian cooperation in the field of organic agriculture' researched the development, status quo before the war, the current state and marketing

opportunities of organic agriculture in Ukraine. Thus, as of July 2022, about 20% of the territories of Ukraine, including some organic fields and objects of organic production, remained occupied by the Russian Federation. According to the results of the survey, which was conducted from July 6 to 15, 2022 by the association 'Organic Initiative' and the public union 'Organic Ukraine' in order to analyse the situation in the agricultural sector in the 5th month of the war, as well as the plans of market operators for the new marketing season regarding the needs/problems of selling organic products in the 2022/2023 marketing season, it was determined that 69.0% of respondents considered the problem to be low purchasing power, 56.0% – a decrease in demand for organic products, 51.0% - disruption of supply chains, 43.0% problems with the sale of organic products, 22.0% considered access to production facilities a need, 14% - marketing tools.

The key challenges of exporting organic products from Ukraine were logistics: blocked ports, insufficient amount of transport, fuel (shortage and increase in fuel prices), drivers (lack of drivers of non-drafting age), destroyed infrastructure, lack of flights.

A survey on the situation at the enterprises of organic producers in the 5th month of the full-scale war shows that 44.0% of respondents continued to work; 24.0% production was partially stopped, but work continued; 13.0% – the enterprise (land, production facilities, etc.) suffered from the occupation from direct hits, but production resumed; 10.0% - production was stopped for other reasons, but work resumed; 5.0% - the enterprise (land, production facilities, etc.) suffered from occupation or from direct strikes and production was stopped; 4.0% – the enterprise (land, production facilities, etc.) was under occupation (Gulieva, 2022). Within the same survey regarding changes in plans for organic production, it was found that 42.0% of organic producers continued organic production/processing in full; 23.0% would like to continue if the financial component of the enterprise is ensured; 27.0% continued production, but needed a change in marketing and/or sales strategy; 5.0% partially reduced the area under organic production or changed the direction of activity; 3.0% refused organic production during the period of active military operations.

Didovych *et al.* (2023) the necessity of applying risk management tools in organizing the export of Ukrainian organic products is considered. The authors note that in recent years, Ukraine has become an important supplier of organic products to the EU, and despite the full-scale war, in 2022, exports of organic products to EU countries have increased (Didovych *et al.*, 2023).

We agree with the opinion of the authors that clear compliance with the requirements for storage, transportation, processing of organic products and assessment of risks associated with organic products, insurance from the leaders of the freight insurance market, involvement of certification bodies in the certification of products will allow exporters to minimize the likelihood of risks in the process export of organic products.

Koval, Vdovenko, & Zos-Kior (2023) the issue of regulation of rural development for the export of organic agricultural products in the context of the development of international trade and decentralization is investigated. Therefore, the authors in the scientific work note that decentralization can contribute to the development and modernization of the transport infrastructure, which is important for the effective export of agricultural products, and the improvement of the infrastructure ensures fast and uninterrupted movement of goods to international markets (Koval, Vdovenko & Zos-Kior, 2023).

The article 'Participation of International Organizations in Solving the Problems of the Agricultural Sector of Ukraine' analyzes the activities of international organizations in mitigating the problems caused by Russia's military aggression, and also offers scenarios and priorities in solving problems that are important for farming and agribusiness in general (Rajai *et al.*, 2022).

Environmental management of domestic enterprises of organic products

The hostilities have not only affected the ability of organic producers to export organic products, but also have negative consequences for the ecosystem. Therefore, in today's conditions, agricultural business entities should implement environmental management to reduce their impact on the natural environment. The initiative activity of economic entities (environmental management) is directed to the formation and implementation of environmental policy, aimed at the formation and implementation of environmental aspects of activity within the general system of administrative management. We agree with Kundilovska's *et al.* (2019) opinion that the implementation of an

ecological management system at the enterprise allows to increase the level of organicity of the product and achieve the following advantages: reduction of costs associated with the negative impact of enterprises on the environment; the possibility of promoting products and services to international markets; saving raw materials, materials and energy; the possibility of receiving tax benefits; increasing the competitiveness of products; improvement of the company's reputation and formation of a favourable public opinion about the company's activities (Kundilovska *et al.*, 2019).

At the same time, in the work 'Prospects for the Development of Small Agricultural Business Entities in the Market Environment' it is emphasized that the subjects of entrepreneurial activity in order to guarantee the use of modern agricultural technologies, environmentally safe herbicides and pesticides, organic waste in the fields, anti-erosion measures; reduction of emissions into the environment must have a sufficient level of local social responsibility (Sirenko *et al.*, 2022).

Therefore, the systematic approach of organic agriculture helps to mitigate the impact on climate change, promotes adaptation of farmers to climate change, creates sustainable farming systems, and also protects and improves biodiversity, has a positive effect on the protection of natural resources, reducing emissions of harmful substances into the air and water space, preserving the health of employees of enterprises and consumers of products.

#### Materials and Methods

The information base of the research is data from the Ministry of Agrarian Policy and Food of Ukraine, the Office for the Development of Entrepreneurship and Export, the platforms Organic Info and Organic Standard.

In order to understand the problems and prospects for the development of the Ukrainian organic market in the market environment, a forecast of the number of exported products for the period until 2025 was made using statistical analysis methods (average absolute growth, average growth rate, average growth rate). The forecast for L steps (time periods) in advance using the average absolute growth is carried out according to the formula:

$$\widetilde{y_{n+L}} = y_n + L\Delta \overline{y} \tag{1}$$

where  $y_n$  – is the actual value of the indicator at the last n-th point of the series;

L – bias period;

 $\widetilde{y_{n+L}}$  – forecast value of the (n+L)-th row;

 $\Delta y$  – is the value of the average absolute growth.

The forecast for L steps ahead using the average growth rate is carried out using the formula:

$$\widetilde{y_{n+L}} = y_n \times \overline{T}_3 p^L \tag{2}$$

The forecast for L steps ahead using the average growth rate is carried out using the formula:

$$\widetilde{y_{n+L}} = y_n \times (\overline{T_{np}} + 1)^L \tag{3}$$

#### **Results and Discussion**

In Ukraine, in accordance with the order of the Cabinet of Ministers of Ukraine dated March 28, 2018 No. 199 'On the establishment of the state institution 'Office for the promotion of exports of Ukraine', the Office for promotion of exports in Ukraine was created and transferred to the sphere of management of the Economic and Financial Department of the Secretariat of the Cabinet of Ministers on the basis of the order of the Cabinet of Ministers of Ukraine dated September 2, 2020 No. 1071 'Some issues of the integral property complex of the state institution 'Office for the promotion of exports of Ukraine'.

In accordance with the protocol decision of the Cabinet of Ministers of Ukraine dated March 10, 2021, the state institution 'Office for the Promotion of Exports of Ukraine' was renamed the 'Office for the Development of Entrepreneurship and Exports'.

The purpose of the Office for the Development of Entrepreneurship and Export is to promote the development of the potential of Ukrainian exporters of organic products, to promote organic exports, as well as to create a positive image of Ukraine as a reliable supplier of organic products abroad.

In 2021, Ukraine adopted the National Economic Strategy until 2030, the purpose of which, in addition to the goal of increasing organic agricultural land, is to increase the export of organic products to 1 billion dollars USA for the period until 2030.

In general, despite the full-scale war, Ukraine managed to preserve the organic sector, diversify its products and attract new participants to the organic market.

The impact of the war on the work of producers of organic products at the beginning of 2022 was manifested through:

- instability of demand and falling prices for organic products;

- significant costs for processing products and increasing electricity tariffs;

- untimely delivery of production elements;

- difficulties in ensuring production with packaging materials;

- problems with crossing the border, long queues at the border, protests;

- the impossibility of continuing certain production processes due to the mobilization of workers.

Exports of domestic organic products in 2022 remained almost at the same level as in 2021, falling by less than 6% 'Figure 1'.



Figure 1. Implementation of Ukrainian organic agricultural products on the foreign market in 2016-2022.

In 2021, the total export of Ukrainian organic agricultural products amounted to 261,000 tons worth 222.0 million dollars USA. In the product structure of exports, the largest specific weight was occupied by corn (80.0 thousand tons for 22.0 million US dollars), soybeans (65.0 thousand tons for 59.0 million US dollars) and wheat (29.0 thousand tons for 14.3 million US dollars). Most organic products were exported to Europe – 82%, North America – less than 17%, Asia – more than 1%. In 2022, despite the full-scale invasion of the Russian

Federation on the territory of Ukraine, the total export of Ukrainian organic agricultural products amounted to 245,600 tons worth 219.0 million dollars USA. In the commodity structure of exports, the largest specific weight was occupied by corn, soy and wheat. Sunflower oil, sunflower cake, sunflower, barley, rapeseed, millet, etc. were also exported. Most organic products were exported to Europe -95% (including the EU -85%, other European countries -10%), North America -4%, Asia -1% 'Figure 2'.



Figure 2. The most exported organic products from Ukraine to the EU in 2021–2022, tons.

According to the European Commission, in 2022, 219,000 tons of organic agro-food products were imported to the EU from Ukraine, thus Ukraine took a leading position among the exporting countries to the EU.

In 2021, the total volume of organic products exported from Ukraine to the EU in value terms amounted to 160.0 million dollars USA, and in 2022 - 184.0 million dollars USA 'Figure 3'.

Other products					·····		
Concentrated apple juice							
Walnut kernel							
Barley	9						
Elderberry is frozen							
Sunflower	222						
Sunflower oil		2/2/					<b>2022</b>
Blueberries are frozen				l			⊠2021
Rapeseed							- 2021
Sunflower cake		22					
Wheat (including spelled)		2					
Soy			2 <b></b>	0.0.0.0			
Corn							
	0	10	20	30	40	50	60
			Million	dollars US	А		

Figure 3. The most exported organic products from Ukraine to the EU in 2021–2022, million dollars USA.

Organic products were exported from Ukraine to European countries, mainly by rail and road transport. The volume of exports by ships has decreased, and it has become impossible to export by air.

In 2022, the largest importers of domestic organic products were the Netherlands, Germany, Austria, Poland, Lithuania, Italy, the Czech Republic, and others (Table 1). Thus, in 2022, 101.0 thousand tons of Ukrainian organic products worth 46.1 million dollars USA were exported to the Netherlands, Germany imported 33.1 thousand tons of organic products worth

35.6 million dollars USA, Austria received 27.3 thousand tons worth 35.8 million dollars USA, Poland – 13.4 thousand tons worth 22.3 million dollars USA, Lithuania – 10.6 thousand tons worth 5.2 million dollars USA, Italy – 6.3 thousand tons worth 9.9 million dollars USA, Czech Republic – 5.0 thousand tons worth 10.2 million dollars USA, Bulgaria – 5.0 thousand tons worth 4.1 million dollars USA, Romania – 2.2 thousand tons worth 1.7 million dollars USA, to France – 2.1 thousand tons worth 6.7 million dollars USA.

Table 1

Top To importers of Okramian organic products in the EO in 2022					
Country	Volume, tons	Cost, million US dollars			
Netherlands	101000	46.1			
Germany	33100	35.6			
Austria	27300	35.8			
Poland	13400	22.3			
Lithuania	10600	5.2			
Italy	6300	9.9			
Czech Republic	5000	10.2			
Bulgaria	5000	4.1			
Romania	2200	1.7			
France	2100	6.7			

Top 10 importers of Ukrainian organic products in the EU in 2022

In January 2023, 30,358.26 tons of organic agricultural products were exported, of which 16,478.35 tons were grain crops, 8,814.56 tons were oil and protein crops, 1,657.30 tons were fruits and nuts, 1,229.80 tons were oil cake, 907.19 tons were beverages, and 825.41 tons were processed products grain, 243.71 – vegetable oils, 103.10 – other products, 81.50 – honey, 17.33 – vegetables.

In January 2023, 23914.88 tons (78.78%) of organic products were exported by road transport, 6245.38 tons (20.57%) by rail, and 198.0 tons (0.65%) by water transport. 13,600.52 tons of organic grain crops, 5,447.01 tons of oil and protein crops, and 1,229.80 tons of oil cake were exported by road transport. 198.0 tons of vegetable oils were exported by water transport, and 2877.83 tons of grain crops and 3367.55 tons of oil and protein crops were exported by rail.

Most organic products are sent by road to the Netherlands (12,277.19 tons), Germany (3,868.92 tons), Italy (2,144 tons), etc.

Ukrainian organic products were exported to France by water transport (198.0 tons). 4101.65 tons were exported by rail to Austria, 1406.74 tons to Switzerland, and 736.99 tons to Germany.

In recent years, Ukraine has become an important exporter of organic products to the EU and the world market, including products with high added value. The Top 6 exporters of organic products with added value include: the company 'Ukroliya' (Poltava region) -aproducer of organic high-oleic and linoleic sunflower oil, as well as organic cake; LLC 'Agrofirma Pole' (Cherkasy) - producer of organic millet to EU countries; LLC 'Krasnohirsky Oil Plant' is a manufacturer of a wide range of products, including unrefined sunflower and rapeseed oil, sunflower and rapeseed cake, sunflower husks; LLC 'Skyrskiy kombinat hliboproduktiv' (Cherka region) - producer of various cereals, flour, as well as flour for baby food; LLC 'Nature Green Ukraine' (Transcarpathian region) - cultivation of shiitake mushrooms, royal mushrooms, gray mushrooms, yellow, pink, and Japanese enoki mushrooms; LLC 'Lilak' (Chernivetska region) - production of organic birch juice.

In 2023, there were five organic brands on the shelves of global retail chains: 'Family Garden', 'Organic Milk', 'Brancho', 'Spring Drops', 'Rud/Eskimos Organic'.

In 2022, 'Family Garden' suffered destruction and theft of its fixed assets during the month-long occupation of the village by Russian invaders, but the enterprise recovered quickly enough and had a successful export season. Due to the war, Organic Milk faced the closure of export markets in the Persian Gulf countries and an increase in production costs, but the company expanded its export potential to EU countries.

The company 'Rud/Eskimos Organic' suffered destruction of warehouses and commercial equipment during the war, and also experienced a power outage from the fall of 2022.

In the conditions of a full-scale war, Ukraine maintains a leading position in the export of organic products thanks not only to the work of producers of organic products, but also to the constant search for ways to stabilize and overcome logistical difficulties. Such a situation in the future will make it possible to fulfil the tasks of the National Economic Strategy until 2030 regarding increasing the volume of export of organic products.

With this in mind, a forecast of the value of organic agricultural products exported by Ukraine for 2023-2025 was made (Table 2). Therefore, the results of the forecasting give reasons to claim that in the period up to 2025, the value of agricultural products exported by Ukraine will increase. Thus, the forecast value of the average absolute increase until the end of 2025 is 289.2 million dollars USA, which is more than the 2022 indicator of the study by 70.2 million dollars USA. In order to promote exports to foreign markets, the Office for the Development of Entrepreneurship and Exports provides entrepreneurs and exporters with assistance in supporting small and medium-sized enterprises; establishment of partnership and cooperation between domestic and foreign businesses; promotion of domestic goods and services in the external market environment; development of export competencies of domestic business.

Table 2

Calculation of forecast values of the value of agricultural products exported by Ukraine		
(million US dollars)		

Vears		Estimated values for:	
i cars	average absolute growth	average growth rate	average growth rate
2023	$\hat{\mathbf{y}}_{2023} = 219.0 + 1 \times 23.4 = 242.4$	$\hat{\mathbf{y}}_{2023} = 219.0 \text{ x } 1.165^1 = 255.2$	$\hat{\mathbf{y}}_{2023} = 219.0 \text{ x} (0.165 + 1)^1 = 255.2$
2024	$\hat{\mathbf{y}}_{2024} = 219.0 + 2x23.4 = 265.8$	$\hat{\mathbf{y}}_{2024} = 219.0 \text{ x } 1.165^2 = 297.3$	$\hat{\mathbf{y}}_{2024} = 219.0 \text{ x} (0.165 + 1)^2 = 297.3$
2025	$\hat{\mathbf{y}}_{2025} = 219.0 + 3x23.4 = 289.2$	$\hat{\mathbf{y}}_{2025} = 219.0 \text{ x } 1.165^3 = 346.4$	$\hat{\mathbf{y}}_{2025} = 219.0 \text{ x} (0.165 + 1)^3 = 346.4$

In addition, the Business and Export Development Office actively supports and organizes various events for organic exporters, including Biofach (Nuremberg, Germany), Anuga (Cologne, Germany) and Middle East Organic & Natural Products Expo (Dubai, UAE). Thus, the companies-exhibitors of the National Pavilion of Ukraine at Biofach 2024 became: LLC 'Avis' (Vinnytsia Region), LLC 'Agrofirma 'Pole' (Cherkasy Region), PE 'Galex-Agro' (Zhytomyr Region), LLC 'Dnipropetrovsk Food Company' VYZ (Dnipropetrovsk region), Danube Agrarian LLC (Odesa region), Catanzaro Eurasia LLC (Odesa region), D.S. Kolchanov LLC (Meetty) (Poltava region), Lickberry LLC (Kyiv region), LLC 'Natsy' (Slow Walnuts) (Transcarpathia region), LLC 'Organic Export' (Honey of Ukraine) (Kyiv region), LLC 'Organic original' (Ekorod) (Kyiv region), LLC 'Ukrvolnat' (Khmelnytsk region), LLC 'Halsey Tradition' (Kyiv region), LLC 'Khimex LTD' (ProOrganica) (Kyiv region).

In order to develop organic production and circulation of organic products in Ukraine in the future, the Ministry of Agrarian Policy and Food of Ukraine closely cooperates with Switzerland within the framework of the program 'Development of trade with higher added value in the organic and dairy sectors of the economy' (QFTR) and 'Organic trade for development in Eastern Europe' (OT4D); Germany – within the framework of the project 'German-Ukrainian cooperation in the field of organic agriculture' (COA); EU – within the framework of the project 'Institutional and political reform of small-scale agriculture in Ukraine' (IPRSA).

Organic Standard has been operating in Ukraine since 2007 – the first Ukrainian certification body for organic production, which also provides export support services and explains the requirements of international standards. In 2023, 'Organic Standard': an educational video course was created on the requirements of EU organic legislation - Regulation 848/2018; the first certification body entered into the official State register of certification bodies in the field of production and circulation of organic products in the Ministry of Agrarian Policy and Food of Ukraine; the first certification body accredited by NAAU for certification under Ukrainian organic legislation; certification according to the new ISCC standard - the global certification system for sustainable development has begun.

#### Conclusions

In the conditions of a full-scale war, Ukraine maintains a leading position in the export of organic products thanks to the work of producers of organic products and the constant search for ways to stabilize and overcome logistical difficulties.

Compliance with the requirements for storage, transportation, processing of organic products and assessment of risks related to organic products, insurance from the leaders of the freight insurance market, involvement of certification bodies in the certification of products will allow exporters to minimize the likelihood of risks in the process of exporting organic products (Didovych *et al.*, 2023).

The research carried out by the authors allows us to draw the following conclusions:

- 1. The general state of export of organic agricultural products by domestic organic producers in the studied period generally has an upward trend; however, in 2022, exports decreased by almost 6%.
- 2. The main challenges faced by exporters of organic products in the conditions of military aggression are: disruption of supply chains, and therefore problems with the sale of organic products (blocked ports, insufficient amount of transport, fuel, drivers, destroyed infrastructure, lack of flights).
- 3. Military actions affected the export of organic products due to: instability of demand and falling prices for organic products; significant costs for product processing and an increase in electricity tariffs due to systematic power outages; untimely delivery of production elements; problems with crossing the border, long queues at the border, protests.
- 4. According to the results of the forecasting of the value of the export of agricultural products of Ukraine for the period until 2025, it was established that the value of the export of agricultural products in the average absolute period until the end of 2025 will amount to 289.2 million dollars USA, which is more than in 2022 by 70.2 million dollars USA, and it is a positive trend on the way to the realization of the target increase in the value of exports of organic products of Ukraine by 2030.
- 5. Ukraine has the potential to develop organic production and grow its export, which is confirmed by the statistical information analyzed in the research process, as well as the list of programs supporting Ukraine by international partners, and

the constant popularization of organic products at international exhibitions.

6. Organic Standard – the certification body for organic producers is a catalyst for positive changes in the organic segment, as exporters of organic products have the support of the internal certification body (including according to the new ISCC standard) regarding issues of export and entering the external market environment.

7. The development and strengthening of the export potential of organic products of Ukraine in the future will contribute to the increase of biodiversity and the reduction of greenhouse gas emissions in comparison with traditional agriculture and to ensure the gradual recovery of the ecosystem from the consequences of military actions.

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## THE POTENTIAL OF BALTIC SEA ALGAE AS AN AGRICULTURAL RESOURCE ENHANCING SUSTAINABILITY IN LATVIA

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#### Abstract

One of the main objectives for the Baltic Sea regions is the harmonisation of the economic development and environmental sustainability. The identification of knowledge-intensive bioeconomy as one of the primary fields of the strategy for smart specialization (RIS3) in Latvia indicates the transition to sustainable and climate neutral approach for the development of Latvia. The strategy aims to promote a more sustainable and efficient use of natural resources, to create high added value, to promote coordination of export and economic interests with environmental protection. This is a multi-faceted and complex process. A scientifically sound approach is needed to develop the most appropriate solutions. The article examines algae biomass as a potential for renewable resources in the agriculture of Latvia in the context of sustainability. The research is aimed at exploring the potential of the Baltic Sea algae as a sustainable agricultural resource in Latvia, focusing on its impact on cultivated plants during the study. The potential is being assessed by conducting a practical study in two stages. The results of the study confirm the potential use of Baltic Sea algae as an agricultural resource in Latvia, which requires further evaluation of the effect of the liquid digestate fraction on crop green mass to determine its potential applicability in agriculture using algal biomass.

Key words: algae, Baltic Sea, agricultural resource, sustainable development, Latvia.

#### Introduction

In the context of the knowledge-based bioeconomy (KBBE), the value chain includes the organization of economic activities connected to the bioeconomy sector, including the use of knowledge flow, innovation and the use of biomass circulation. The bioeconomy aims to create new value chains for the product groups that are traditionally based on nonrenewable resources, for example, oil, natural gas, coal, chemical substances, etc. However, short-term profits and globalized production are often prioritized in the global value chains of the bioeconomy, which may hinder the use of biomass circulation. In order to achieve a sustainable and circular bioeconomy, traditional linear value chains (Kircher, 2021; Grinberga-Zalite & Zvirbule, 2022) need to be modified and adapted.

Rising attention is being paid towards the implementation of the circular bioeconomy principles across different value chains. The central element of bioeconomy is the formation of the integrated value chains and prevention of obstacles in the sectors, emphasizing the importance of sustainability controlled by value chains (Aggestam & Giurca, 2022).

The Ministry of Agriculture of the Republic of Latvia has proposed measures to solve problems in the agricultural sector, stressing the need for innovation, sustainability and efficient supply chains. These measures serve as an answer to several problems, including rising costs of production, low yield rate, shortage of manpower and uncertainty for future (OECD, 2019).

Addressing the issues of the agricultural sector requires an integrated approach in a multidisciplinary context. The purpose of this research is to analyze the potential of the Baltic Sea algae as a sustainable agricultural resource in Latvia and evaluate its impact on cultivated plants during the study. To achieve the purpose of the research, following tasks were drafted: 1) to characterise the use of algae a sustainable natural resource in the guidelines and the directions of previous research; 2) to sample macroalgae in the Latvian coastal area of the Baltic Sea region to determine the extent of leaching and to identify species suitable for agricultural use; 3) to conduct controlled experiments to assess the impact of Baltic seaweed as an algal digestate extract on seed germination and health in order to quantify the benefits.

#### **Materials and Methods**

In the theoretical discussion of the study on the role of algae as a potential agricultural resource for sustainable development in Latvia, 19 sources were analyzed using the monograph method. To establish the potential use of algae in the agriculture of Latvia, two laboratory evaluations were performed in collaboration with Latvia University of Life Sciences and Technologies and the laboratories of the Liepaja University. Both of these researches complement each other establishing validations and a succession of iteration processes, and reaching technologic readiness level TRL3/TRL4. The results of the research were collected by using qualitative and quantitative methods of analysis. Case study was performed by using laboratory analysis and experiments. Data from tests and experiments were grouped and analyzed in order to determine connection between the objects under research.

#### **Results and Discussion**

A Clean Planet for all is a long-term strategic vision of European Commission for a climate neutral economy that includes using algae (European Commission, 2018). Blue Growth of European Union (EU) is a longterm strategy to support sustainable growth in the marine and maritime sectors. The driving forces of the European economy are seas and oceans; thus, they have a huge potential for innovations and growth. One of the visions of the strategy – improvement of environment, publicly available bioproducts, eco-

#### THE POTENTIAL OF BALTIC SEA ALGAE AS AN AGRICULTURAL RESOURCE ENHANCING SUSTAINABILITY IN LATVIA

services, building a favourable consumer position for the usage of algae (Johnson, 2018). Referring to the joint project of Kurzeme planning region, GRASS and INTERREG - an overview of the regulation of cultivation, collection and storage of macroalgae in Latvia, documentation information strategy for sustainable bioeconomy in Europe, EU strategies for the Baltic Sea region, correspond with the strategies and initiatives mentioned above (Kurzeme planning region, 2021). In Latvian Bioeconomy Strategy 2030, section under the Bioresources - Fisheries, states that: 'the sea biopotential that has not been used in Latvia so far, including seaweed, mussels, and algae which may be used, for example, in chemical and pharmaceutical industry' (Latvijas Republikas Zemkopības ministrija, 2018).

Algae to a large extent is an unused resource. Algae can be used to limit carbon footprint in production of food, feed, medicines, biodegradable plastics, fertilizers, growth stimulators, innovative products, biogas and biofuel. Most of the political documents approbate cultivation options for different kind of algae species in sea regions. This is a commendable action, because cultivation of algae does not compete with agricultural land (Lee, Noh, & Khim, 2020).

The topic of algae biomass use is also topical in other Baltic States and in the Baltic Sea region as a whole. The existing scientific research basis about the use of algae currently offers different research discourses, for example, a joint group of researchers from Estonia, Latvia, Poland and Germany evaluated the potential place of algae in the overall ecosystem and the created value chain in Eastern Baltic Sea region of Maritime Spatial Planning. These authors stress that cultivation of algae and further processing already exist in Europe, but there has been no social and spatial acknowledgement. This endangers the achieving of the sustainability goals, because they create interdisciplinary overlaying (Armoškaitė *et al.*, 2021).

Since the 1940s algae has been a resource for producing hydrocolloid in Baltic states. Estonia is one of the Baltic states that has maintained this production to this day. This is affected by sustainability in production processes. The authors emphasize that it is essential to evaluate and search for solutions for minimizing non-sustainable algae production in the value chain (Weinberger *et al.*, 2019).

Vytautas Magnus University researchers V. Vitunskienė, A. Aleksandravičienė, J. Čaplikas and A. Dapkuvienė have concluded that the potential of production of algae in Lithuania is being studied, especially for the production of biofuel and other bioproducts. Cultivation of algae in Lithuania include both traditional and innovative methods, for example, open pond systems and closed photobioreactors. The country's approach for algae cultivation is affected by geographic and climatic conditions, as well as its commitment to use sustainable and renewable energy resources. Regardless of the potential, cultivation of algae in Lithuania faces challenges such as the need for more efficient and profitable cultivation and harvesting methods. Nevertheless, the strong agricultural foundation of the country, availability of biomass and ongoing research on improvement of cultivation methods for algae open considerable options for the development of algae bioeconomy (Vitunskienė *et al.*, 2023).

Whereas L. Pastare in her research underlines the positive environmental impact using a digestate (a by-product of biogas production) as a substitute for chemical fertilizers, it is concluded in the research that algae are a promising resource for sustainable energy production. However, additional research is necessary to solve the problems and optimize the respective processes (Pastare *et al.*, 2014).

Hence the author concludes that the current scientific research basis about the use of algae in the Baltic states is diverse and covers various aspects starting from environmental impacts and ending with possible commercial usage. Although there are still imperfections in research that need to be prevented to comprehend and use alga potential fully in these regions taking into account interdisciplinary approach within the ecosystem.

In the first stage of the author's research, the potential of the renewable natural resource available in Latvia – algae – was evaluated in increasing the crop capacity of agriculturally cultivated plants. During the research macroalgae samples were collected in the Baltic Sea region across the seacoast of Latvia in 5 areas: Pate, Liepāja, Pāvilosta, Kolka and Mērsrags. The collection of samples is reflected in 'Figure 1'.



Figure 1. Sample collecting in Mersrags.

25 samples were taken within polygons of 1 m x 20 m by footstep of five meters. Re-sampling was being performed in November of the same year in order to compare the seasonal change in algae composition. During the research algae washout volume was also determined. From Kolka to Engure it is little 0,1 m<sup>3</sup>/100 m. On the West coast of the Gulf of Riga the volumes are increasing from the North to the South. During the summer washout volume of macroalgae on exposed parts of the coast in Pāvilosta is 17 m<sup>3</sup>/100 m. In autumn, the washout volume of macroalgae is  $0 - 2.54 \text{ m}^3/100 \text{ m}$ , and in most cases, it is less than 1 m<sup>3</sup>/100 m, except for Liepāja, where it reached the maximum of the season  $-228 \text{ m}^3/100 \text{ m}$ . The collected biomass of algae was dried in the environment of laboratory and calculations were drawn about separate species and their dry weight (DW). The calculations about the drawn calculations of the separate species and the place of sample collection are summarized in Table 1. Crude ash substance was determined for the samples collected. In this case crude ash, on a provisional basis, indicate on samples more contaminated with sand particles or on the contrary the cleanest samples. The degree of grinding of the samples varied: fine, coarse, medium. On a provisional basis, the lowest admixture of sand particles was found in the coarsely grind

samples collected in Liepāja, because the crude ash contents were the lowest. Both the algae species dominating in the sample, and the degree of grinding plays an essential role in the high degree of purity. The samples collected in Liepāja were dominated by Furcellaria lumbricalis that have less grains of sand on its surface and do not flatten when drying, the mass does not become dense. After grinding the samples, finer admixtures are easier to separate by sifting, but heavier ones can be separated using gravity. Samples from Liepāja and Pape, which have similar botanical composition and proportions of species, could not be ground to a powdered consistency as other samples by the methods used in the study. This may indicate potential issues in the selection of the aggregate state of the product and in the production process.

Table 1

0.0000

0.1091

Estimates of individual algae species at different sampling points in summer 2021, DW%					
Genus	Species	Pape	Mērsrags		
Cladophoraceae	Cladophora glomerata	0.0685	0.3085		
Cladophoraceae	Cladophora glomerata	0.2458	0.1788		
Cladophoraceae	Ulva intestinalis	0.0000	0.0805		
Cladophoraceae	Ulva prolifera	0.0073	0.0982		
Potamogetonaceae	Battersia arctica	0.0000	29.3100		
Potamogetonaceae	Elachista fucicola	0.0004	0.1626		
Potamogetonaceae	Fucus vesiculosus	0.0000	3.0521		
Potamogetonaceae	Ceramium virgatum	0.0027	0.0055		
Potamogetonaceae	Coccotylus truncatus	0.0343	0.6963		

Furcellaria lumbricalis

Vertebrata fucoides

Source: author's calculations.

Potamogetonaceae

Potamogetonaceae

In order to determine the biomass potential of algae, it is necessary to determine the exchangeable acidity. The exchangeable acidity is determined by potentiometric manner, the methodology used for determining reaction in peat. The analysis was performed in two reruns for each version of the average samples. The obtained results indicate insignificant differences between the analysed versions; therefore, there is no need for in-depth repeated analysis by extracting more versions. The collected data demonstrate that algal biomass material has a weak acid reaction, which is optimal for use in most soils and crops in Latvia. About 40% of the soils are acidic and slightly acidic in Latvia (pHKCl<6.0), and the average soil pH is 6.2 (State Plant Protection Service of the Republic of Latvia, 2021). Algae contain macroelements and microelements, amino acids, vitamins, plant hormones cytokinin, auxin (Craigie, 2011) and abscisic acid (Khan, 2009). The benefits of using algae and their products include stimulation of seed germination, increase yield growth, plant root growing, plant tolerance

to various stress conditions, drought, high soil acidity) and promoting plant resistance to disease and attacks of pests (Eyras, Rostagno, & Defossé, 2013). There are many species of sea algae and their various extracts thereof that have been tested to contain various plant diseases and pests before they harm plants. Plant pathology studies have been showing positive results about the effect of induced resistance for plant defence system against pathogens by sea algae extracts (Pourakbar et al., 2021). Algae remedies are used for reducing abiotic or non-living natural factors created (temperature, water deficiency, increased EC) and biotic (caused by living organism pathogens) stress on plants (Tuhy, Saeid, & Chojnacka, 2020). Results of the first stage of the research and information available in theory suggest the potential of the algae species Furcellaria lumbricalis as a plant growth enhancer – a biostimulator.

13.1102

2.2861

The author's objective of the second stage of the research was to determine the algae species

Furcellaria lumbricalis impact as a biomass on sowing of the cultivated plants with anaerobic fermentation. At this stage, a prototype of algae extract was developed in laboratory conditions, involving several stages: (1) collection of biomass - 251 of algae was manually harvested on February 6, 2022; (2) biomass pre-treatment – purified under laboratory conditions using 201 container; (3) anaerobic fermentation -251of algae was placed in a 301 biogas fermentation plant in a container equipped with electric heating and thermostat (accuracy  $\pm$  0.5 °C) with a working temperature of 50 °C; (4) extraction of the liquid fraction of digestate - on February 20, 2022, the liquid fraction of digestate was strained manually, which ensured anaerobic fermentation of 14-day algal biomass. The first four steps of the second stage are graphically reflected in 'Figure 2' within the yellow border. Additionally, it reflects its possible adaptation to production conditions. Blocks outside the yellow border and resource flow biostimulator under the laboratory production process is not included, but indicate on possible use in production, drying, in ensuring bioreactor processes and the production of by-products. The biogas obtained during the production process is recommended to be used in order to maintain the processes of the production, for example, to use the electricity generated in the cogeneration plant for temperature control of the bioreactor, and the heat produced by the cogeneration plant - in drying of the algal biomass, in cases if there are remains of collected biomass after inserting in the

production size bioreactor, so the remained algal biomass does not start decomposition process in the stall. For the production of biogas from macroalgae, the incorporation of Furcellaria lumbricalis has been carried out prior to the development of a prototype of algae extract. In the pilot study: Production of biogas from sea algae and wine production waste biogas extraction processes have been compared with and without identical setting of inoculum. Both experiments produced highly different amounts of biogas and methane content ratios that indicate the beneficial effects of winery residue on anaerobic fracturing of algal material. Respectively the experiment performed confirms that the fermentation system made of Furcellaria Lumbricalis algae detritus and wine production waste, is a promising project for biogas production. However, there is restrictive environmental and social aspect – sea algae detritus and inoculum seasonal availability (Zaimis, 2018). This aspect should be taken into account in the future development of sea algae products and is recommended to find the most suitable and available inoculum that will increase extraction of biogas and quality of the potential end product, and also would be suitable for use in agriculture, ensuring the products higher added value. (5) liquid fraction obtained is diluted in different concentrations: 12%, 6% un 3% and evaluation is being made on 320 seeds of cultivated plant basil in an automated greenhouse, where the plants are provided with steady and controlled growing conditions.



Figure 2. Entering and exiting resource flows for the production of prototype.

Observation data were registered, and data analysis was made by photo fixation method. The course of evaluation of initial impact on cultivated plants: 1) prepared plastic pots for seedlings, filling with equal amounts of substrate in each pot and precisely 8 seeds, in total 80 seeds for each concentrate, (2) prepared concentrates – 120 ml diluted on 11 of water (1:8) 12% concentrate, 70 ml diluted on 11 of water (1:14) 6% concentrate and 30 ml diluted on 11 of water (1:33) 3% concentrate. Samples of dilutions are reflected in 'Figure 3'.



Figure 3. Liquid fraction of the diluted digestate.

30 seedling pots, each has 8 seeds, treated with the concentrates, 10 pots of seedlings for each concentrate test. 10 reference pots of seedlings that are not treated with the concentrate. The diagram of evaluation of initial impact on cultivated plants is pictured in 'Figure 4'. (3) Once a week, pots of seedlings are treated with water and twice a month with concentrate of liquid fraction.

REF. 0 %	KONC. 3 %	REF. 0 %	KONC. 3 %	REF. 0 %	KONC. 3 %	REF. 0 %	KONC. 3 %	REF. 0 %	KONC. 3 %
KONC. 6%	KONC. 12%	KONC. 6%	KONC. 12%	KONC. 6%	KONC. 12%	KONC. 6%	KONC. 12%	KONC. 6%	KONC. 12%
REF. 0 %	KONC. 3 %	REF. 0 %	KONC. 3 %	REF. 0 %	KONC. 3 %	REF. 0 %	KONC. 3 %	REF. 0 %	KONC. 3 %
KONC. 6%	KONC. 12%	KONC. 6%	KONC. 12%	KONC. 6%	KONC. 12%	KONC. 6%	KONC. 12%	KONC. 6%	KONC. 12%

Figure 4. Chart of seedling pot setting. Each pot with 8 basil seeds, in total 320 basil seeds were used for the evaluation.

At the first time of data collection, i.e. 03.03.2023 the pots of seedlings that are treated with 12% of liquid fraction concentrate, seeds were sprouted most of all: 47 from 80, compared to other concentrates. The condition of seedlings on the first data collection can be viewed in 'Figure 5'.



Figure 5. Progress of seed sprouting 03.03.2023.

At the second time of data collection, i.e. 06.03.2023 most growth of the seedlings was established on the pots of seedlings treated with 3% concentrates - 24 new sprouts in three days. The reference pots and pots of seedlings treated with 6% concentrate, approximate growth of 20 sprouts. Seedling pots treated with 12% concentrate showed the smallest growth -5 sprouts. At the third time of data collection, i.e. 10.03.2023 the largest growth in seedlings is observed in the reference pots of seedlings - 9 sprouts. The second largest increase is observed in the seedlings of pots treated with 3% concentrate, with 5 new sprouts. The smallest growth in seedling pots treated with 6% and 12% concentrates – 4 to 5 sprouts. On 17.03.2023 seedling pots, excluding the reference pots (treated with water) were treated with the respective concentrate. At the fourth time of data collection, i.e. 24.03.2023 no change in the growth was observed in the seedlings of pots treated with 3% concentrate. Growth is observed in the reference pots with 2 new sprouts. New sprouts continued to grow in the seedlings of pots treated with 6% and 12% concentrates of liquid fraction. The condition of seedlings on the fourth data collection can be viewed in 'Figure 6'.



Figure 6. Course of seed germination in the seedling pots 24.03.2023.

After 29 days since the seeding, the fixed data were collected and summarized in Table 2. Pots of seedlings treated with 12% concentrate showed the fastest growth rate at the beginning of the evaluation and the largest number of sprouts at the end of the evaluation -78.75%.

Table 2

The evaluation results of the initial impact on cultivated plants (basil) in 2023

		<b>L</b>	· · · ·	/	
Prototype	03.03.	06.03.	10.03.	24.03.	Germination
%	pcs	pcs	pcs	pcs	power %
0	32	51	60	62	77.50
3	25	49	56	56	70.00
6	29	51	56	60	75.00
12	47	52	56	63	78.75

Source: author's calculations.

The reference pots of seedlings treated only with water, with no added liquid fraction, showed the second-best results of sprouted seedlings at the end of the evaluation. The rate of germination was steady during the whole time of evaluation. Germination percentage rate is 1.25% lower. It should be taken into account that the evaluation was performed on a small scale, the percentage difference is expected to be higher when scaling the experiment. The data obtained in the seedling pots treated with 6% concentrate are lower than the reference seedling pots, germination of seeds was steady. At the end of the evaluation the smallest growth of seeds was observed in the seedling pots treated with the 3% concentrate compared to higher concentrations of the liquid fraction; however, there was an interesting growth pattern – the seedlings sprouted later than seedlings in the pots treated with 6% and 12% concentrates. Following the initial evaluation, it can be concluded that the use of the 12% concentrate accelerates germination of seeds in the beginning stages, which cannot be said about the use of the 3% and 6% concentrates. This means that the visible effect of the liquid fraction prototype, according to the current data, works from the use of 12% concentrate. It should be noted that it is not clear to what extent the concentrate affects the volume of green mass of the plant over a longer period of time. It is positive that plants that are treated with liquid fraction concentrates of 3%, 6% and 12% have a visually higher stress resistance to drought before watering. The treated plants are not visibly wilted, whereas plants in the reference seedling pots are evidently wilted.

#### Conclusions

1. The author's analysis of theoretical literature confirms that the main problems currently arise from the use of non-renewable resources in harmonizing economic development and environmental sustainability in Latvia. Conversely, Baltic Sea algae is a largely untapped renewable resource whose potential studies are topical in order to move towards achieving the climate neutrality objectives. There is a research gap about circular economy-based use of algae with an integral approach of the bioeconomy to the overall ecosystem in order to exploit the full potential of the value chain in creating the added value.

- 2. Empirical studies carried out by the author in 2 stages acknowledge that on the Kurzeme coast of the Baltic Sea the algae species according to calculated data *Furcellaria lumbricalis* shows the second highest dry weight potential of 13.11 DW%, have less grains of sand on its surface and do not flatten and have low acid reaction, which is optimal for use in most soils of Latvia, with a wider probability of aggregate state when being commercialised.
- Experiments conducted in the study on crop seeds indicate that 12% digestate liquid fraction concentrate delivers faster germination versus the 3% versus 6% concentrates. Overall germination rate for 12% concentrate versus 3% concentrate is 12.5% higher, but versus 6% concentrate is higher for 5%. Whereas visual observations show that plants treated with 3%, 6% and 12% digestate liquid fraction increase resistance to drought.
- 4. In reference to the obtained data in the empirical research, the author sees the perspective in future studies to evaluate the impact of the liquid fraction of digestate on the green mass of cultivated plants in order to determine its potential use in agriculture using algae biomass.

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## HEALTH SELF-EVALUATION: ARE THERE DIFFERENCES IN RURAL AND URBAN TERRITORIES IN LATVIA

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#### Abstract

Recent developments in politics and economy has created additional challenges for medical institutions with lack of medical personnel, transportation from rural areas to medical institutions. Very often, there is a difference between medical services in urban and rural areas. In research is often mentioned that male and female persons have different evaluations on their health situation. The aim of the paper is to prepare research based recommendations for possible steps for public administrators to support availability of medical services in urban and rural areas. Tasks of the current research: analysis of theoretical findings reflected in scientific publications and discussion of research results, analysis of tendencies of self-perceived health status of population in Latvia, analysis on possible differences between gender as in scientific publications is often mentioned that female and male persons have different evaluations, analysis of health self-evaluations between inhabitants in rural and urban territories and possible differences in evaluations for persons with different employment status. Representative data from EU-SILC, different statistical analysis methods and statistical indicators are used: indicators of descriptive statistics, cross-tabulations, testing of statistical hypotheses with t-test and analysis of variance – ANOVA, chi-square test, as well as correlation analysis. Research results confirm that self-perceived health status in Latvia are higher in rural areas and higher health self-esteem evaluations were made by female persons.

Key words: health self-evaluation, rural territories, well-being, employment, municipalities, public administration.

#### Introduction

Recent pandemic has caused many challenges and serious influences which have reflections also after the pandemic. Besides, there are increasing problems and challenges with administrative reform in Latvia. In many cases it results in lack of medical personnel especially in rural areas as well as in lack of availability to access medical doctors. In this paper, there are analysed tendencies of self-perceived health status for inhabitants in rural areas and conducted comparisons on self-perceived health status by male and female persons, by inhabitants in rural and urban areas. In research results, it is often noted that those evaluations differ by gender. Academic researchers world-wide have paid attention to self-perceived health status influence on different society reactions (Callard & Friedli, 2005; Wang & Lu, 2017; Reisinezhad & Fakhrahmad, 2023) with research based suggestions for possible practical use in decision making. Researchers have noted that several generations and age groups of inhabitants need special attitude and attention with specific solutions and approaches (Manthorpe & Cornes, 2004; Léveillé & Chamberland, 2010; Lin & Chou, 2022; Chen et al., 2022). Researchers have noted that arts and other aspects have influence of self-perceived health status (Secker et al., 2007; Seimuskane, Vilka, & Brekis, 2017; Gordon et al., 2018). Technology and information technologies development influence several health service providers (Yusif, Hafeez-Baig, & Soar, 2020: Daugėlienė, 2020; Šimanskienė, Labanauskaitė, & Montvydaitė, 2022; Salkovska et al., 2023; Danusevics et al., 2023; Sergejeva & Zeidmane, 2023; Zhang et al., 2023). Researchers suggest paying certain attention to several important aspects: religion (Jiang & Zheng, 2015) and other aspects (Romanova et al., 2018; Solin et al., 2019; Muravska & Dyomkin, 2020). Several aspects are for attention (Andersone et

*al.*, 2019; Behmane, Rutitis, & Batraga, 2021; Chan & Chen, 2023). Several advanced methods and approaches are used to find deeper analysis results (Braslina *et al.*, 2020; Zhang *et al.*, 2021; Sun & Li, 2022; YahiaMarzouk & Jin, 2023) with interesting and innovative solutions and research-based suggestions which could be practically used for decision-making and best solution finding also in other countries.

#### **Materials and Methods**

For empirical data analysis, there were used data files of EU-SILC survey data which are collected annually in all European Union countries and EU candidate countries by the same methodology prepared by Eurostat. Obtained data are for representative sample and could be used for deeper analysis. Authors have used this opportunity to examine differences about health esteem by urban and rural inhabitants, by male and female persons. The health self-esteem was evaluated in scale 1-5, where 1 – very good; 2- good; 3 – fair; 4 – bad; 5 – very bad. Statistical data analysis was carried out using SPSS software which allow many important analysis realization and a lot of calculations in foreseen aspects: by gender, by territory (rural or urban) and other selected analysis using descriptive statistics: indicators of central tendency or location: arithmetic mean, mode, median of the evaluations by respondents; indicators of variability: range, standard deviation and standard error of mean. For data analysis, cross-tabulation to find distributions of evaluations by gender, by territories (urban and rural) and by other indicators was used. For data analysis, correlation analysis to find relationships among analysed aspects was used too.

#### **Results and Discussion**

Main statistical indicators of descriptive statistics of self-perceived health status are reflected in Table 1.

	Table 1
Main statistical indicators of self-perceived	health
status in Latvia in 2022	

S	tatistical indicator	Value
N	Valid	9564
IN	Missing	0
Mean		2.68
Standard Error of Mean		0.009
Median		3
Mode		2
St	andard Deviation	0.853
Range		4
Minimum		1
	Maximum	5

Source: Authors' calculations based on EU-SILC data.

Data indicate that in Latvia most of inhabitants have evaluated their health as good (characterized by mode with value 2); half of inhabitants have evaluated their health as fair or better and half of inhabitants have evaluated it as fair or worse, characterized by median with its value 3. Arithmetic mean of the evaluations on health self-esteem was 2.68. All range of the scale was used for evaluations. Distribution of evaluations on

health self-esteems is reflected in Table 2.

Table 2

Distribution of evaluations on self-perceived he	alth
status in Latvia in 2022	

Evaluations	Frequency	Percent	Valid Percent	Cumulative Percent
1- Very good	367	3.8	3.8	3.8
2 - Good	4140	43.3	43.3	47.1
3 - Fair	3587	37.5	37.5	84.6
4 - Bad	1173	12.3	12.3	96.9
5 - Very bad	297	3.1	3.1	100.0
Total	9564	100.0	100.0	

Source: Authors' calculations based on EU-SILC data.

Data indicate that 43.3% of inhabitants have evaluated their health as good, 47.1% of inhabitants have evaluated their health as very good or good, and only 3.1% of inhabitants in Latvia have evaluated health as very bad. Distribution (cross-tabulations by urban and rural areas and by gender) of evaluations of health selfesteems of inhabitants of Latvia in 2022 are included in Table 3.

Table 3

Distribution of evaluations on self-perceived health status by territories in Latvia in 2022						
	Evaluations	TERRI	TORY	Total		
	Evaluations	Urban	Rural	Total		
1.17 1	Count	149	54	203		
1-Very good	% within TERRITORY	5.8%	3.6%	5.0%		
	Count	1257	695	1952		
2-Good	% within TERRITORY	48.8%	45.9%	47.7%		
2.5.1	Count	866	544	1410		
3-Fair	% within TERRITORY	33.6%	36.0%	34.5%		
	Count	242	182	424		
4-Bad	% within TERRITORY	9.4%	12.0%	10.4%		
5-Very bad Total	Count	63	38	101		
	% within TERRITORY	2.4%	2.5%	2.5%		
	Count	2577	1513	4090		
	% within TERRITORY	100.0%	100.0%	100.0%		
1-Very good	Count	125	39	164		
	% within TERRITORY	3.4%	2.1%	3.0%		
	Count	1473	715	2188		
2-Good	% within TERRITORY	40.3%	39.4%	40.0%		
2.5.1	Count	1430	747	2177		
3-Fair	% within TERRITORY	39.1%	41.1%	39.8%		
	Count	497	252	749		
4-Bad	% within TERRITORY	13.6%	13.9%	13.7%		
	Count	132	64	196		
5-very bad	% within TERRITORY	3.6%	3.5%	3.6%		
	Count	3657	1817	5474		
Total	% within TERRITORY	100.0%	100.0%	100.0%		
	Distribution of I-Very good 2-Good 3-Fair 4-Bad 5-Very bad 1-Very good 2-Good 3-Fair 4-Bad 5-Very bad 5-Very bad 5-Very bad	Distribution of evaluations on self-perceivedEvaluationsEvaluationsCount% within TERRITORYCount% within TERRITORY% within TERRITORYCount% within TERRITORY% within T	Distribution of evaluations on self-perceived health status by tTERRI TERRIEvaluationsUrbanUrbanIPERRITORY1-Very goodCount149% within TERRITORY5.8%Count1257% within TERRITORY4.88%Count242% within TERRITORY3.6%3-FairCount2.4%Count2.4%TotalCount2.4%1-Very badCount1473% within TERRITORY3.4%Count1430% within TERRITORY3.4%Count1430% within TERRITORY3.4%Count1430% within TERRITORY3.4%Count1430% within TERRITORY3.6%Count1430% within TERRITORY3.6%Count1430% within TERRITORY3.6%Count1430% within TERRITORY3.6%	Distribution of evaluations on self-perceived health status by territories in LatviTERRITORYInterritories in CountInterritories in CountInterritories in Count1-Very goodCount149Count1257695% within TERRITORY48.8%45.9%Count1257695% within TERRITORY48.8%45.9%3.6%3.		

Source: Authors' calculations based on EU-SILC data.

Table 6

Data indicate that the shares of evaluations of good and very good are higher in evaluations by urban persons in comparison with rural persons; other evaluations are alike for urban and rural persons and by gender. The question is - does the shares of evaluations for each gradation differ statistically significantly – this aspect is evaluated by chi-square. Results of chi-square tests are included in Table 4.

Table 4

Main statistical indicators testing differences on evaluations by chi-square in urban and rural territories of self-perceived health status in Latvia in 2022

Statistical indicators	Value	df	Asymp. Sig. (2-sided)		
Pearson Chi-Square	20.242 <sup>a</sup>	4	0.000		
Likelihood Ratio	20.982	4	0.000		
Linear-by-Linear Association	9.702	1	0.002		
N of Valid Cases 9564					
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 103.41					

Data indicate that the shares in those groups do not differ statistically significantly. Results on correlation analysis are reflected in Table 5.

Table 5 Main statistical indicators of correlation analysis on evaluations of self-perceived health status in Latvia in 2022

		GENERAL HEALTH	Gender	TERRITORY
H. H	Pearson Correlation	1	0.100**	0.032**
ENER HEALT	Sig. (2- tailed)		0.000	0.002
6 H	Ν	9564	9564	9564
sr	Pearson Correlation	0.100**	1	-0.039**
Gende	Sig. (2- tailed)	0.000		0.000
	Ν	9564	9564	9564
JRY	Pearson Correlation	0.032**	- 0.039**	1
ERRITO	Sig. (2- tailed)	0.002	0.000	
II.	Ν	9564	9564	9564
**. C	orrelation is sig	gnificant at the	0.01 level	(2-tailed).

Source: Authors' calculations based on EU-SILC data.

Data indicate that correlation coefficients are statistically significant with high probability for all analysed aspects. Next step for analysis it was to investigate - what are the health self-esteem evaluations by persons in rural areas in Latvia. The results of evaluations by descriptive statistics are included in Table 6.

Data indicate that the evaluations of health esteem by rural persons are lower than in Latvia.

Main statistical indicators descriptive statistics or	n
self-perceived health status rural areas	
in Latvia in 2022	

S	tatistical indicators	Values			
N	Valid	3330			
IN	Missing	0			
Mean		2.71			
Standard Error of Mean		0.015			
Median		3			
Mode		2			
Standard Deviation		0.840			
Range		4			
Minimum		1			
	Maximum	5			

Source: Authors' calculations based on EU-SILC data.

Data indicate that in Latvia 42.3% of inhabitants in rural territories in Latvia have evaluated their health as good, 45.1% of inhabitants have evaluated their health as very good or good, only 3.1% of inhabitants in rural territories have evaluated health as very bad.

Table 7

#### Distribution of evaluations on self-perceived health status in rural territories of Latvia in 2022

Evaluations	Frequency	Percent	Valid Percent	Cumulative Percent
1-Very good	93	2.8	2.8	2.8
2-Good	1410	42.3	42.3	45.1
3-Fair	1291	38.8	38.8	83.9
4-Bad	434	13.0	13.0	96.9
5-Very bad	102	3.1	3.1	100.0
Total	3330	100.0	100.0	

Source: Authors' calculations based on EU-SILC data.

Main statistical indicators on self-perceived health status in rural areas of Latvia by gender are included in Table 8.

#### Table 8 Main statistical indicators of descriptive statistics on self-perceived health status in rural areas by gender in Latvia in 2022

8									
Gender	Ν	Mean	Standard Deviation	Standard Error Mean					
Male	1513	2.64	0.833	0.021					
Female	1817	2.77	0.841	0.020					
Source: Authors' calculations based on FU-SUC data									

Source: Authors' calculations based on EU-SILC data.

Data indicate that in rural territories male persons evaluate their health as better, but whether those evaluations are statistically different is analysed by ttest, see Table 9.

Table 9

# Main statistical indicators of t-test differences in average evaluations on self-perceived health status in rural areas by gender in Latvia in 2022

Variances	Levene Equality	e's Test for of Variances	t-test for Equality of Means				
	F	Sig.	Т	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Equal variances assumed	1.594	0.207	-4.560	3328	0.000	-0.133	0.029
Equal variances not assumed			-4.565	3230.879	0.000	-0.133	0.029

Source: Authors' calculations based on EU-SILC data.

Data of results of t-test indicate that there are differences in averages of evaluations of self-esteem by male and female persons in rural territories in Latvia, but the differences in evaluations do not differ statistically significantly.

#### Conclusions

- 1. Persons' feeling about their health situation is important to keep well-being of persons and make them socially active participants of society.
- 2. Academic research results reflected and scientific publications indicate that there is different self-perceived health status by male and female persons as well as that they are different in rural and urban territories.
- 3. Data analysis results indicate that in Latvia evaluations of self-esteem in rural and urban areas do not differ statistically significantly.
- 4. Female and male inhabitants in rural territories in Latvia evaluations of self-perceived health status do not differ statistically significantly.

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## THEORETICAL OVERVIEW OF SELF-EMPLOYED PERSONS

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#### Abstract

Employment is a crucial indicator of economic development and growth, making employment policy a key component of national and regional socio-economic strategies. Self-employment is a significant form of employment widely practiced in Latvia and other EU Member States as a means to initiate businesses and integrate into the labour market. As of 2022, about 27.66 million self-employed individuals, constituting roughly 14% of the EU workforce, contribute to the European economy. Modern work dynamics allow individuals to earn income as employees or self-employed, with flexible employment forms, including self-employment, gaining popularity due to several advantages. These advantages include increased flexibility, personal independence, opportunities to join or stay in the labour market, and the potential to earn additional income alongside a primary job. However, self-employment also has its drawbacks. It can be exploited to evade taxes and bypass labour laws, leading to 'false self-employment'. While this may appear advantageous for the self-employed, it primarily benefits employers by reducing their costs. This practice can severely limit the self-employed's access to social protection and adversely impact their quality of life and financial stability in situations of social risk, such as illness, disability, or retirement. Self-employment involves various economic, psychological, sociological, and managerial dimensions and entails considerable risk. Global trends indicate that individuals in lower-income countries are more likely to be self-employed, whereas those in higher-income countries tend to have paid employment.

Key words: self-empoyment, independent workers, taxable status.

#### Introduction

Self-employment is a hot topic, related to more than 1.57 billion self-employed people worldwide. The self-employed account for half of all employees. Tax issues for the self-employed are complex, leading to various problems. These include difficulties in preparing tax returns, incorrect calculation of tax payments, insufficient information on tax reliefs and deductibles. There may be difficulties with paying social security contributions. Such problems often result from a lack of information, complex legal requirements or misinterpretation of information.

The theoretical aspect of self-employment covers a wide range of topics, from economics, sociology to psychology. It includes understanding how individual entrepreneurs build and manage their businesses, the motivations for self-employment, the challenges and the impact on the wider economy.

From an economic perspective, self-employment is seen as an important source of micro-entrepreneurship and innovation. Self-employment contributes to economic diversification, creates new jobs and stimulates competition. Theory also examines how self-employment is related to insufficient labour market flexibility or as a defence mechanism against Simon C. Parker's study 'The unemployment. Economics of Self-Employment and Entrepreneurship' offers a deep insight into the economics of self-employment, including motivations and potential risks (Parker, 2004).

Sociology studies self-employment as a social and cultural phenomenon in which individual goals, social networks, cultural norms and values play an important role. Entrepreneurship is seen not only as an economic activity, but also as a way for individuals to demonstrate their identity and values (The Psychology of Entrepreneurship, 2023). Researcher Mariana Mazzucato, in her study 'The Entrepreneurial State. Debunking Private Sector Myths' looks at the role of the state in innovation and in supporting self-employment. Psychology studies the personality traits, motivations and behaviour of the self-employed. Self-employment is often associated with high autonomy, notions of self-efficacy and a desire for achievement. Psychological factors can influence an individual's ability to start and successfully run their own business. Psychology Research Progress series provides an overview of the psychology of entrepreneurship, highlighting personality traits and motivation (The Psychology of Entrepreneurship, 2023).

The impact of legal structures and the tax system on self-employment is an important theoretical aspect influencing the design of the business environment. It also includes discussions on how public policies and regulation can facilitate or hinder the growth of selfemployment (Gomez, Isakov, & Semansky, 2015).

Problem Statement: the existing tax frameworks for self-employed individuals in Latvia and other OECD countries are complex and inconsistent, leading to difficulties in compliance, inadequate social protection, and potential economic inefficiencies. While some countries have introduced simplified tax schemes and digital solutions, others lag behind, resulting in a competitive imbalance and varied entrepreneurial success rates.

The research aim is, on the basis of the studies of type of employment self-employed policy in Latvia, to compare it with other countries.

The following research tasks are subject to the aim:

- 1) to analyse statistics on self-employment in the world;
- 2) to demonstrate the importance of paying taxes on the income of the self-employed;
- 3) to develop recommendations for self-employment status and taxation.

The research basically covers the period from 2000 to 2024.

#### **Materials and Methods**

Research methods: the monographic and descriptive methods, analysis and synthesis, the graphic method and case studies from different countries. The present research is based on various scientific publications, publicly available documents, information available in databases and other sources.

The study mainly uses and analyses tax legislation from different countries focusing on real examples of taxation.

#### **Results and Discussion**

## Global trends and self-employment taxation

Tax competition for the self-employed is an important issue when studying globalisation trends. Tax competition for the self-employed is a phenomenon that arises when countries seek to attract or retain entrepreneurs and the self-employed by offering particularly favourable tax regimes or incentives. Such competition is common across countries and regions of the world. There are a number of factors that influence tax competition for the self-employed (Martinez-Vazquez, 2021):

#### Tax rates

Some countries offer lower tax rates for the selfemployed, which can attract self-employed workers and entrepreneurs from other countries or encourage existing entrepreneurs to stay at home.

#### Tax incentives and rebates

Countries can offer various tax incentives and rebates to the self-employed, such as reduced tax rates for the first years of business or exemptions from certain taxes in certain circumstances.

#### **Business environment support**

Some countries provide active support to entrepreneurs, for example, through free training, financial assistance or infrastructure for business development.

#### Administrative formalities

Countries that simplify administrative formalities for entrepreneurs and reduce red tape can be more attractive to the self-employed.

Competitive tax policies can be positive, because they can stimulate economic development by attracting new entrepreneurs and boosting business activity. However, it can also have negative consequences, such as a lack of spending for the public budget (Hagen & Sørensen, 1994). It is therefore important that countries carefully consider and assess the long-term impact of competing tax policies and how this will affect their economic development and national budgets. To ensure fair tax competition, some countries have introduced international tax standards and cooperation initiatives to prevent tax evasion and avoidance (Gilkerson *et al.*, 2003).

International tax policy coordination for the selfemployed is a topical issue. In an era of globalisation and the rise of digital businesses, international tax policy coordination is increasingly important to prevent tax avoidance and ensure fair competition.

'Figure 1' shows that the share of self-employed compared to the employed varies. Moreover, it depends on the economic situation of the country. By definition, the self-employed work for themselves, without recourse to wage labour. In Latvia, the number of self-employed who pay state social contributions is around 45,000.

In newly developed countries, the majority of people are poor and become self-employed to escape poverty (Selfemployment and poverty in developing countries, n.d.).

When looking at the state of self-employment around the world, it is clear that there is in fact an inverse correlation between the share of self-employed workers and their countries' GDP. According to the International Labour Organisation, only 12.2 per cent of workers are self-employed on average in highincome countries, while in low-income countries this figure rises to 80.3 per cent. This is a measure of the prevalence of subsistence farming and the number of people who work unpaid for their family businesses (also listed as self-employed in the data).



Figure 1. Self-employment rate 2022, % of total employment in OECD counties. Source: OECD date. https://data.oecd.org/emp/self-employment-rate.htm.

In 2019, Niger had the highest self-employment rate in the world - over 95 percent. Arab countries had the lowest self-employment rates. 4.9 per cent of workers in the United Arab Emirates earned their wages independently in 2019. In Kuwait and Qatar, the figures were even lower - 1.8 per cent and 0.4 per cent respectively (Statista data, n.d.).), see 'Figure 2'.



0% 20% 40% 60% 80% 100%



Source: Statistics / International Labour Orgaziation via World Bank, https://www.statista.com/chart/18908/selfemployed-workers-by-country/.

The Covid-19 pandemic, the cost-of-living crisis and the war in Ukraine have impoverished 165 million people over the past three years, the UN reported on Thursday. These shocks will have pushed 75 million people into extreme poverty earning less than \$2.15 ( $\notin$ 1.92) a day between 2020 and the end of 2023, and another 90 million below the poverty line of \$3.65 ( $\notin$ 3.26) a day, according to a study released by the UN Development Programme (UNDP) (LSM.lv).

## Self-employment model in Scandinavian and Anglo-Saxon countries

The regulation of the self-employed in the Nordic and Anglo-Saxon countries offers two different approaches that influence the business environment, tax policy and social protection.

Broad social protection is the main feature of the Scandinavian model. For example, Sweden, Norway and Denmark offer extensive social protection, which includes sickness benefits, pensions, unemployment benefits and parental leave. Social protection systems are designed to ensure equal access to all labor market participants, including the self-employed (Ulmestig, 2013).

Scandinavian countries are characterized by a high tax burden. High income tax rates to fund extensive social safety net programs. The tax system promotes income redistribution to reduce inequality and support socially vulnerable groups (Engström & Holmlund, 2009).

The Nordic countries have introduced various programs and support measures to promote entrepreneurship and innovation. It also includes help and advice for the self-employed. The self-employed can count on stable social protection that reduces the risk associated with income fluctuations and ensures greater social equality and prosperity for all citizens. The high tax burden may be a disincentive for some entrepreneurs seeking lower tax regimes.

The main features of the Anglo-Saxon model are the low tax burden. A simplified tax system exists in the USA, Great Britain and other Anglo-Saxon countries. The Anglo-Saxon model usually has lower tax rates and simpler tax administration procedures. A lower tax burden stimulates entrepreneurship and selfemployment as it reduces the financial burden on entrepreneurs.

Social safety net programs are less extensive, and the self-employed are often responsible for their own health insurance and retirement savings. Less government intervention in the labor market and social safety net programs, allowing for greater flexibility (Simoes, Crespo, & Moreira, 2016).

Anglo-Saxon countries have fewer regulatory barriers, making it easier to start and run a business. Various public and private initiatives are available to provide financial and advisory support to entrepreneurs (Yuen *et al.*, 2018).

The authors come to the conclusion that a lower tax burden makes these countries attractive to entrepreneurs and investors. Greater flexibility and fewer regulatory barriers encourage innovation and rapid adaptation to market changes.

Less social protection may lead to greater economic insecurity for the self-employed, especially in crisis situations. Less income redistribution can contribute to greater social and economic inequality.

The authors conclude that both the Scandinavian and Anglo-Saxon models have their own advantages and disadvantages, and each model offers different solutions for promoting and regulating selfemployment. The Nordic model is characterized by strong social protection and equality, but with a higher tax burden, while the Anglo-Saxon model offers lower taxes and greater flexibility, but with less extensive social protection. The choice between these models depends on the political, economic and social priorities of each country.

In Latvia, 418,000 or 22.5% of the population were at risk of poverty in 2021 - 0.9 percentage points less than in 2020, according to the 2022 population survey conducted by the Official statistical portal (Oficiālais statistikas portāls), their disposable income was below the poverty line.

The authors explore how to promote the transition of the unemployed to self-employment and what strategies and policies to use. To encourage the growth of self-employment, support is needed from the state, from local authorities and from non-governmental organisations. The authors propose important steps that can help the unemployed to become selfemployed:

• *Entrepreneurship training programmes* providing knowledge on business planning, financial management, marketing and sales. Such programmes are often offered by publicly
supported institutions or private organisations (Osterwalder & Pigneur, 2010).

- Online courses from platforms like Coursera, Udemy or Khan Academy, which offer a wide range of courses on entrepreneurship and specific skills.
- Seed capital from public funds, European Union programme support or microfinance institutions to help with start-up costs (Ries, 2011).
- *Tax breaks and* subsidies for start-ups to reduce the financial burden in the first years of operation.
- *Mentoring programmes* that connect young entrepreneurs with experienced mentor entrepreneurs, giving them the opportunity to learn from the experience and mistakes of others.
- *Business incubators* that provide not only financial support but also office space, mentoring and access to investment networks.
- *Entrepreneurship promotion* policies that facilitate business registration, tax payment and other administrative processes.
- *Sector-specific support programmes* that stimulate demand in priority sectors by offering specialised support and training.

Promoting these initiatives and resources can help the unemployed not only to become self-employed, but also to start their own businesses and become entrepreneurs in the future.

## Taxation and self-employment

The study found that governments should support selfemployment as a means to create livelihood opportunities for the poor and expand earning opportunities. Too often, government policies discourage the self-employed and, if policies are right, the self-employed can increase their incomes and lift themselves out of poverty.

## Tax implications for the state budget

An examination of the taxation of the self-employed in individual countries (China, Japan, Austria, USA) shows that most countries impose personal income tax, national social security contributions and value added tax on the self-employed. Let us examine each of these taxes:

*Income tax contributions:* self-employment income makes up a significant part of the country's total tax revenue. The higher the number of self-employed and the higher the level of their income, the higher the income tax revenue for the state budget.

- *VAT contributions*: Self-employed persons who sell goods or services are responsible for collecting and paying VAT. This tax is an important source of revenue for the national budget, contributing to the share of consumption tax revenue.
- Social security contributions: Social security contributions paid by the self-employed help finance a wide range of social services, including pension and health care programmes. Contributions are vital to ensure the long-term financial sustainability of these programmes.

Tax policy is also much discussed in OECD research: the Organisation for Economic Co-operation and Development (OECD) regularly conducts research on the economic impact of tax policy, providing recommendations and analyses of tax systems around the world.

## Alternative taxation for the self-employed and innovative solutions

The authors carried out a study from different counties to explore alternative tax models for the self-employed in order to simplify the tax process, reduce the administrative burden and promote fair and efficient tax collection. Alternative taxes are designed to ease the tax burden and simplify tax administration for the self-employed:

- *Flat tax:* a simple tax system with a single fixed rate for all income, regardless of its amount. This model can simplify the tax calculation and declaration process for the self-employed (Mitchell, 2006).
- *Automatic withholding* may apply to selfemployed workers who provide services to businesses. The company withholds the tax from the time of payment and transfers it to the Treasury, reducing the administrative burden for the selfemployed.
- *Simplified annual tax:* An alternative model that allows the self-employed to pay tax on the basis of annual income rather than detailed records of expenditure and income (Bartlett, 2012).
- *Tax credits and incentives:* tax incentives for investments in innovation, education or other development activities. Such incentives can encourage business and personal development.
- *Digital tax remittance:* using modern technologies such as blockchain and artificial intelligence to automate the calculation and payment of taxes, reducing the likelihood of errors and fraud (Fichtner & Feldman, 2015).
- *Micro-enterprise tax.* In some countries, selfemployed and micro-businesses have the option of paying a special micro-business tax which combines several taxes into one simplified payment.
- *Patent payment*. A patent payment is a fixed annual payment that allows a self-employed person to carry out an economic activity in a specific field without the complexity of calculating and declaring taxes.
- *Fixed monthly payment*. In some countries, selfemployed workers can pay a fixed monthly payment that includes all taxes and social contributions, thus facilitating tax administration.

Innovative solutions for self-employed taxation can include various technological and procedural improvements aimed at simplifying the tax process, improving financial planning and providing userfriendly access to information (Tyson, 2015). These solutions can significantly reduce the administrative burden of taxation and help the self-employed manage their finances more effectively.

Based on the research carried out, the authors propose some of these innovative solutions:

- *Digital accounting software:* Software that automatically records income and expenses, calculates taxes and prepares tax returns, such as QuickBooks, FreshBooks and Xero. These types of solutions allow the self-employed to manage their finances and taxes more efficiently.
- *Cloud computing:* allows self-employed workers to access their financial data and accounting information from any device with an internet connection, providing flexibility and mobility.
- *Payment integration:* integrating payment systems with accounting software can automate income recording and reduce the need for manual entries.
- Offers personalised tax advice based on user data and using artificial intelligence algorithms. This can help identify tax savings and optimisation opportunities.
- Online tax advice platforms: provide access to professional advice online, offering a convenient way to get specific advice and answers to questions (Kohler, 2015), and offers courses on accounting, tax planning and financial management tailored to the self-employed.

Main problems in self-employment taxation:

- Tax complexity and bureaucracy. Tax systems are often complex and require a significant investment of time and resources to understand and comply with the requirements. This can be particularly problematic for the self-employed, who must take full responsibility for tax calculations and payments.
- *Tax burden*. The self-employed often have to pay both personal income tax and social security contributions, which together can result in a high tax burden compared to wage earners. This can create financial pressure and motivation to operate in the informal economy to avoid taxes.
- *Irregular income*. The self-employed often have irregular income, which can make accurate tax calculation and planning difficult. This can make it difficult to maintain liquidity and pay taxes on time.
- *Insufficient information and support.* Many selfemployed people lack knowledge of tax laws and obligations. Insufficient access to information and support can lead to errors in tax returns and increase the risk of penalties.
- *Lack of social protection.* The self-employed often do not receive the same social protection guarantees as wage earners, such as sickness benefits or pensions. The high tax burden can seem particularly unfair if the social protection system is not equivalent.

## Conclusions

1. The taxation of the self-employed in different countries is an important aspect influencing the business environment, economic activity and individual motivation to start a business.

- 2. Global trends and policies indicate how countries support the self-employed, how taxation is applied, what the new perspectives are and what the challenges are.
- 3. Tax contributions from the self-employed are an important source of revenue for the national budget, as they include both direct taxes, such as income tax, and indirect taxes, such as value added tax (VAT) on the sale of goods and services. In addition, depending on the country, self-employed workers may also pay national social security contributions.
- 4. Digitisation and automation are important and more and more countries are introducing digital tax return systems for the self-employed, which automate many manual processes, reducing the administrative burden and making it easier to pay taxes.
- 5. In an era of globalisation and the rise of digital businesses, international tax policy coordination is increasingly important to prevent tax avoidance and ensure fair competition.

The taxation of the self-employed is a major issue that requires attention from both policymakers and the self-employed themselves. Simplification of the tax system, tax incentives, better information and education, more flexible payment mechanisms and improved social protection can help to alleviate these problems and promote business development.

## Proposals

To improve self-employment the government should focus on key challenges:

- 1. Evaluate the introduction of alternative taxation for the self-employed to simplify the tax payment process, reduce the administrative burden and promote fair and efficient tax collection, and facilitate the tax calculation and declaration process for the self-employed.
- 2. Introduce automatic withholding tax. Automatic withholding tax can be applied to the self-employed who provide services to businesses. The company withholds the tax from the moment of payment and transfers it to the Treasury, reducing the administrative burden for the self-employed.
- 3. Introduce simplified tax schemes. Some countries have introduced simplified tax schemes for small businesses and the self-employed, offering lower tax rates or simplified ways of calculating taxes to encourage entrepreneurship.
- 4. Explore tax incentives for the self-employed. In some countries, tax incentives and other incentives are available to support new entrepreneurship, innovation and the use of green technologies among the self-employed.
- 5. Introduce digitisation and automation. More and more countries are introducing digital tax return systems for the self-employed, which automate many previously manual processes, reducing administrative

burdens and making it easier to pay taxes.

6. Simplify tax schemes: some countries have introduced simplified tax schemes for small businesses and the self-employed, offering lower tax rates or simplified ways of calculating taxes to encourage entrepreneurship.

7. Evaluate the integration of social protection. Integrate the self-employed into social security systems, offering them equal access to health care, pensions and other social protection programmes.

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## CORPORATE SOCIAL RESPONSIBILITY OF AGRICULTURAL COMPANIES OF UKRAINE UNDER MARTIAL LAW

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## Abstract

One of the main factors thanks to which the Ukrainian economy withstood the powerful beginning of the full-scale military invasion of Russia and has been maintaining courage for more than two years, is the high level of social initiatives of business and self-awareness of Ukrainian society. Agricultural companies not only protect their business, but also continue to work to support the army, their workers, communities and vulnerable population. The article analyses the features of the implementation of corporate social responsibility as a modern business strategy. The specifics of corporate social responsibility practices of agricultural companies have been established, which is aimed at: socio-psychological and financial support for company employees; ensuring the defence capability of the Armed Forces of Ukraine and related structures; humanitarian assistance to internally displaced persons and vulnerable populations; support of territorial communities in the regions of presence. New directions of CSR, the emergence of which was a direct consequence of the war, have been identified and systematized. It has been established that these include: additional emergency leaves; military leaves with retention of compensation; regular emotional check-ins in teams; 'Ukraine first' case, 'National Identity' case, 'Ukraine Culture Code' case. It was determined that the essence of these new cases is meaningful national education, support of national identity, raising the level of awareness of Ukrainian cultural heritage and debunking myths about 'Soviet' Ukraine. Furthermore, it was established that the emergence of such practices is connected with a clear understanding of Ukrainian society about the need to rebuild the state after the victory.

Key words: corporate social responsibility, agricultural companies, war, practices, financial support, humanitarian aid.

### Introduction

Russia's unprovoked armed aggression against Ukraine has created a number of systemic problems of security, socio-humanitarian, economic а and environmental nature that require detailed research and understanding. Russia's attack is a challenge for domestic business, which positions itself as socially responsible and declares its commitment to moral and ethical principles. The military actions and occupation of the territories of Ukraine by the Russians have already caused multibillion-dollar damage and caused unprecedented problems in all areas of the socioeconomic system of the state, which creates space for the implementation of initiatives by socially responsible business entities aimed at supporting the Ukrainian people and the army of Ukraine.

It is also predictable that the reconstruction of the state in the post-war period will also require the consolidation of the efforts of Ukrainian society and big business, and will require complex and responsible decisions of the authorities of Ukraine. Under these conditions, business has the opportunity to confirm its commitment to the principles of corporate social responsibility (hereinafter referred to as CSR). Especially these theses concern the national agrarian business, which continues to be budgetforming during the war. It is large agricultural companies that have been the leaders in the implementation of CSR in recent decades, as indicated by world ratings such as the Dow Jones Sustainability Index (DJSI), FTSE4 Good Index, and Corporate Philanthropy Index (CPI).

Regardless of the fact that the war unleashed by Russia has been going on for quite a long time, it should be noted that scientists have not yet fully explored the peculiarities of the functioning of the mechanism and instruments of corporate social responsibility in combat conditions. Therefore, there is a need to consider these issues in more detail in order to enable domestic socially responsible companies to adapt to realities and further support various social projects.

The purpose of this study is to establish the specifics of the instruments of the corporate social responsibility mechanism that emerged during the war in Ukraine, in the context of different groups of beneficiaries, at whom the practice of CSR is aimed.

The aforementioned purpose led to the implementation of the following tasks:

- to analyse the specifics of implementing corporate social responsibility as a modern business strategy;
- to identify the specifics of corporate social responsibility practices of agricultural companies, aimed at: socio-psychological and financial support for company employees; ensuring the defence capability of the Armed Forces of Ukraine and related structures; humanitarian assistance to internally displaced persons and vulnerable populations; support of territorial communities in the regions of presence;
- to establish new directions of CSR, the emergence of which was a direct consequence of the war.

#### **Materials and Methods**

We investigated the phenomenon of corporate social responsibility of Ukrainian companies in the agricultural sector under the martial law using generally accepted scientific methods, such as: the system analysis method – to generalize scientific approaches in order to establish the features of the practice of applying social responsibility by agricultural business; the method of

statistical analysis – in the process of analysing various aspects of the development of business entities and their impact on social processes; analytical approaches and the method of expert surveys – in diagnosing the spread of various types of social practices and the specifics of their manifestations during the war; the graphic method – for visualization of the received information, its comparison and generalization; the case method – to assess the readiness of companies to make efforts and spend resources to overcome the consequences of military operations, the systematization method – when drawing conclusions of the conducted study.

The study was conducted in Ukraine. The object of the study was the practice of corporate social responsibility of companies in the agricultural sector of Ukraine. The respondents were representatives of the top management of agricultural companies, which, in terms of production size, according to the current legislation of Ukraine, are classified as large enterprises.

The conducted survey highlights the specifics of corporate social responsibility practices of agrarian companies, aimed at: social-psychological and financial support of company employees; ensurance of the defence capability of the Armed Forces of Ukraine and related structures; humanitarian assistance to internally displaced persons and vulnerable sections of the population; support of territorial communities and residents of the regions of presence.

Thirty companies of the agrarian sector of Ukraine took part in the study. Business entities were selected for participation in the survey on a regional basis: 6 companies each from the central, northern, southern, eastern and western regions of Ukraine.

The electronic questionnaire, which was a Google form, was distributed among agricultural companies via the Internet (questionnaires were sent to the e-mail addresses of economic entities posted on their official websites). The survey was conducted from October 2023 to December 2023 inclusive.

Respondents commented on issues related to the following areas:

1. Basic CSR practices of Ukrainian agricultural companies during the war in relation to employees and their families.

2. Basic CSR practices of Ukrainian agricultural companies during the war to ensure the defence capability of the Armed Forces of Ukraine and related structures.

3. The main directions of contributions of Ukrainian business during the war in relation to internally displaced persons and vulnerable categories of the population.

4. The main directions of contributions of Ukrainian business during the war to support territorial communities and residents of the regions of presence.

## **Results and Discussion**

There are many different definitions of corporate social responsibility, which have evolved as historical

circumstances have changed. The CSR concept was first introduced in management literature in the 1950s as 'the obligations of businessmen to pursue those policies, to make those decisions, and to follow those lines of action that are desirable in relation to the objectives and values of our society' (Bowen, 1953). The European Commission (2001) has previously defined Corporate Social Responsibility (CSR) in its Green Paper as 'a concept whereby companies integrate social and environmental concerns in their business operations and in their interaction with their stakeholders on a voluntary basis'. Subsequently, the issue of researching the essence of CSR was considered in works: (Öberseder, Schlegelmilch, & Gruber, 2011; Costanigro, Deselnicu, & McFadden, 2016; Hartmann, 2011). However, there is still no single definition of CSR.

The famous Italian economist Becchetti (2011) formulated a definition of the essence of CSR, which we can give preference to: 'a more balanced sensitivity to a wider range of stakeholders'. The author emphasizes that compliance with the law is part of mandatory good behaviour, while the CSR includes everything that goes beyond legal compliance. Accordingly, a better definition would be one that sees CSR as a change in the scale of priorities of the company in relation to stakeholders. This vision involves a shift from the maximization of shareholder value to a more measured and balanced focus on a wider range of stakeholders, such as consumers, employees, suppliers, local communities and even, in the context of sustainable development, future generations.

Corporate social responsibility has been developing in Ukraine even before the start of the full-scale invasion as an integrated direction of business. According to a study by the Centre for CSR Development in 2018, approximately 80% of Ukrainian companies began to implement CSR or were guided by its principles. But only 25% of them systematically allocated a budget for CSR projects, which significantly distinguished Ukrainian business from international companies, where the figures reach 90-95% (Myskiv & Pasinovych, 2023).

With the outbreak of a full-scale war in Ukraine, the essence and scope of application of CSR practices changed significantly, and it was the war that forced Ukrainian businesses to reorient their programs to support sustainable development. The vast majority of companies have integrated aid and recovery programs of Ukraine into their CSR policies 'Figure 1'.

Corporations in the agricultural sector that responded positively to the major political and social events in the life of Ukraine over the past 20 years (Orange Revolution, Revolution of Dignity, COVID-19 pandemic) already had some experience and were therefore able to quickly adapt to the changes caused by the beginning of a fullscale aggression. The main motive for CSR of such business entities was the unification of Ukrainian agricultural businesses to help their country.



Figure 1. The main sectors of the national economy of Ukraine, which are leaders in the implementation of CSR practices aimed at maintaining the vital activity of the civilian sector and the defence capability of the Armed Forces of Ukraine. *Source: (Official website of CSR Ukraine, 2024).* 

We have studied and evaluated the CSR practices of Ukrainian agricultural companies (which were respondents), which were implemented during 2022-2023 and related to the above areas of activity:

1. Basic CSR practices of Ukrainian agricultural companies during the war in relation to employees and their families.

The impact of the war on the physical and mental health of society turned out to be enormous. The war destroyed all social ties; the opportunity to be safe was taken away from every person; it deprived everyone of confidence in the future; there was no control over the situation. In the first months of the war, every citizen of Ukraine had to learn to cope with powerlessness, helplessness and reestablish their identity in difficult conditions, regaining partial control over their lives, and, at the same time, say goodbye to illusions about the safety and steadfastness of the world in which we live. Part of Ukrainian society is 'stuck' in the traumatic reality, has lost the opportunity to adapt to such extreme conditions of existence. Under such conditions, employer enterprises have been and remain one of the few 'islands' of stability, predictability and confidence in the present.

If before the full-scale war there were enough companies in the agricultural sector of Ukraine that decided not to implement CSR practices and help their employees, now almost every agricultural company pays attention to the areas of improving the well-being of workers and supporting their physical and mental health. The success of business development in the agricultural sector in the conditions of an aggressive war directly depends on whether employees are emotionally stabilized, whether they have a sufficient level of psychological stability, the possibility of physiological recovery and the skills to cope with chronic stress, and at the same time show productivity at work.

The catalog of CSR practices implemented by Ukrainian companies during the war, compiled by CSR Ukraine (national partner of CSR Europe (Brussels, Belgium), and World Business Council on Sustainable Development (Geneva, Switzerland), contains 328 examples, 26 of which are aimed at supporting employees (Official website of CSR Ukraine, 2024). The respondents we interviewed noted that the CSR practices applied at the enterprises they headed after the start of the war to support their employees were in the vast majority of cases (86% of respondents) of an emergency nature (Table 1).

Table 1

CCD amotion	%
CSK practice	of respondents
Relocation or evacuation to safe places	43
Provision of psychological support	19
Provision of financial support	90
Psychological support programs for employees' children	7
Holding meetings to maintain contact within the team	26
Provision of free time to employees to participate in the volunteer movement	68
Implementation of educational projects (education and training, creation of inclusive	87
jobs)	02

CSR practices of agricultural companies implemented since the beginning of the full-scale war aimed at supporting their employees and their families, 2022-2023

Evaluation of the data shown in Table 1 allows us to conclude that the most common CSR practice in 2022-2023 was the provision of financial support to employees by agricultural companies (89.5%), the implementation of educational projects (82.4%) and the provision of free time to employees to participate

in the volunteer movement (68.3%). The least used cases were those related to psychological support for employees and their family members. Such support was practiced by up to 20% of respondents, the vast majority of whom were located in the capital region (Kyiv region) and gravitated toward large urban

agglomerations (agricultural companies in Kharkiv, Dnipropetrovsk and Odesa regions).

Within CSR, agricultural companies began to emphasize well-being and war/work balance. Companies have started implementing work practices during air raid warning, additional emergency leaves if necessary, military leaves with continued pay, regular emotional check-ins in teams. If such practices were just emerging before the war, then after it began, they were rethought and adapted to the new reality of wartime.

Ukraine first, National Identity, Ukraine Culture Code became completely new areas of CSR. These cases are not only about monetary or value support, but also about meaningful national education. Lectures on the history of Ukraine, Ukrainian language courses, a book club on Ukrainian poetry - these are just some of the actively developing projects, because this has become one of the key focuses of the CSR strategy. The goals of such projects can include both supporting national identity, which has been destroyed for centuries, and raising awareness of Ukrainian cultural heritage and debunking myths about 'Soviet' Ukraine. The emergence of such practices is associated with a clear understanding of Ukrainian society about the need to restore the state after the victory.

2. Basic CSR practices of Ukrainian agricultural companies during the war to ensure the defence capability of the Armed Forces of Ukraine and related structures.

Companies of the agrarian sector, starting from the very beginning of the war, were strongly involved in the implementation of CSR practices aimed at supporting the defence capability of the Armed Forces of Ukraine and the structures that ensure their vital activities. During the survey, a fairly wide range of such assistance provided by agricultural companies was revealed (Table 2).

Table 2

## CSR practices of agricultural companies implemented since the beginning of a full-scale war, aimed at maintaining the defence capability of the Armed Forces of Ukraine and related structures in 2022-2023

CSP practice of agricultural companies in 2022 2023	%
CSK practice of agricultural companies in 2022-2025	of respondents
Purchase of defence equipment, body armor, helmets, radio transmitters, heat sensors,	72.3
tactical clothing and footwear	
Purchase of walkie-talkies, gadgets, generators	61.8
Purchase of UAVs of foreign origin	17.4
Financing the development of Ukrainian UAVs	5.8
Purchase and repair of cars and ambulances	18.1
Purchase of mobile repair workshops	4.3
Supply of medicines to meet the needs of hospitals and the Armed Forces of Ukraine	92.5
Purchase of hemostatic agents	43.1
Purchase of turnstiles, sanitary kits	84.6
Donation of blood and plasma to wounded or injured soldiers or civilians	22.7
Equipping medical institutions with simulators for the rehabilitation of soldiers with	8.2
wounded or lost limbs	
Funding of institutions whose activities are aimed at the psychological rehabilitation of	1.4
military personnel	
Food organization of the Territorial Defence Forces of the Ukrainian Armed Forces	69.6

The analysis of the survey data presented in Table 2 allows us to conclude that all CSR practices of agricultural companies aimed at helping the Armed Forces of Ukraine can be divided into 2 main groups: financing of material and technical assistance and organization of medical support and the rehabilitation process. As for the first group of CSR practices, we should note that the material and technical assistance received by the Armed Forces of Ukraine from companies of the agrarian sector for two years was carried out with different emphases, which were set depending on external and internal factors that influenced the provision of the army by the state. Thus, during the first half of 2022, the army of Ukraine needed, along with weapons, appropriate equipment. Therefore, during this period, the focus of CSR practices of agricultural companies was on providing the Ukrainian army with essential items: tactical

clothing and footwear, means of defence, bulletproof vests, helmets, walkie-talkies, etc. After the establishment of the supply process by the Ministry of Defence of Ukraine, the need for such activities almost disappeared, and the emphasis of corporate practices in 2023 shifted to financing the technological and logistical component of the war, and the decrease in US funding and the lack of artillery shells ensured a sharp increase in the procurement of UAVs, especially in the second half of 2023.

As for the emphasis in the second group ('medical' group), it should be noted that the relevance of none of the CSR directions related to medical care has changed. The need for the amount of blood and plasma donations to wounded military or civilians may vary, depending on the degree of activity of hostilities, as well as on the intensity and power of rocket attacks and shelling attacks on peaceful cities of Ukraine.

3. The main directions of contributions of Ukrainian business during the war in relation to internally displaced persons and vulnerable categories of the population.

Cases of corporate social responsibility in relation to internally displaced persons and vulnerable categories of the population, who found themselves below the poverty line, which increased almost 10 times during the first year of the war in Ukraine, come down mainly to humanitarian and, in some cases, financial support 'Figure 2'.



Figure 2. CSR directions of agricultural companies in relation to internally displaced persons and vulnerable categories of the population of Ukraine in 2022-2023.

The evaluation of the results of the questionnaire regarding this type of CSR practices showed that the most popular case among agricultural companies was the provision of humanitarian aid to internally displaced persons and other vulnerable categories of the population in the form of food packages (86.9% of respondents). The practice of issuing various types of humanitarian aid in kind is widespread (51.7%). Also, agricultural companies, especially in the first months of the full-scale invasion, provided those in need with food (38.2%) and housing (23.5%).

4. The main directions of contributions of Ukrainian business during the war to support territorial communities and residents of the regions of presence. The CSR practices of agrarian companies regarding the support of territorial communities in the regions of their presence can be considered as corporate volunteerism, the result of which is the improvement of the financial condition and/or social infrastructure of the united territorial communities. Even before the war, agricultural companies have taken an active part in the support and development of the territories where the production facilities of the companies are located, and with the beginning of the full-scale invasion, such activities expanded due to new practices 'Figure 3'. Corporate volunteering and assistance to territorial communities managed to increase the company's team spirit during a difficult period.

At the beginning of the war, many large agricultural companies paid taxes in advance, which became a significant support for the Ukrainian economy at the level of both state and local budgets.





According to the catalog of company contributions, the total amount of taxes paid in advance as of January 1, 2023 amounted to more than 233.6 thousand euros. We will present some practices of corporate social responsibility of individual Ukrainian agricultural companies, which have been implemented since the beginning of the full-scale invasion (Table 3).

The results of the study show the activities of four agricultural companies of Ukraine, which during 2022-2023 made a significant contribution to strengthening the defence capability of the Armed Forces of Ukraine, support of its own employees, internally displaced persons and other vulnerable sections of the population, reconstruction and development of the regions of its presence. All these companies entered the TOP-20 largest agricultural companies of Ukraine in 2023.

Kernel is Ukraine's largest producer and exporter of grains, the leader in the global sunflower oil market, and the key supplier of agricultural products from the Black Sea region to global markets. The company accounts for about 8% of the world's sunflower oil exports.

The CSR practices of this agrarian company from the very beginning of the war covered almost all possible niches of socially and financially vulnerable categories. The company implements more than 20 cases on an ongoing basis, which allowed it to become one of the leaders of CSR in wartime, to be an example of corporate unity for other representatives of national business.

Table 3

Some examples of CSR practices of companies that are leaders in the agricultural se	ctor
of Ukraine as of January 1, 2023	

Name of the	Revenue,	Loss (-)/		
agricultural	million	Profit, million	Implemented CSR practices	
company	euros	euros		
Kernel	3025.0	- 72.4	Equipment for the military Number of CSR cases – 8 Total amount of assistance – 9786,1 thousand euros Humanitarian food aid Number of CSR cases – 4 Total amount of assistance – 3884,7 thousand euros Medical equipment and medicines Total amount of assistance – 911,3 thousand euros Cars, trucks and other assistance to the Armed Forces of Ukraine (1,421 units) Number of CSR cases – 4 Total amount of assistance – 26215,0 thousand euros Financial assistance from Kernel Number of CSR cases – 4 Total amount of assistance – 11892,0 thousand euros	
Myronivskyi 1994.9		- 196.2	Psychological assistance to employees and their family members Development of personnel potential As of March 1, 2024, 13,509,496 tons of charitable products	
Khliboprodukt			were issued for a total amount of 22.2 million euros	
Astarta	411.1	51.4	Assistance to international and local food and humanitarian missions. Delivery of humanitarian goods of the UN World Food Program. As part of a joint project with the International Labour Organization, the Ministry of Foreign Affairs of Denmark, the Embassy of Denmark in Ukraine and the Federation of Employers of Ukraine, more than 3,500 food packages were formed and delivered to Kharkiv and Mykolaiv.	
Bayer	168.2	11.0	Provision of housing for the company's employees and their families who left the occupied territories and zones of active hostilities Purchase of medicines	

Increasing the social responsibility of business is a significant challenge for the enterprise. On the other hand, it is the basis for improving its image and increasing competitiveness, and therefore it appears as an effective development strategy. Scientists believe that in Ukraine there has always been a latent social capital of a high level, called 'sleeping social capital', which, under the influence of a full-scale invasion, turned into a powerful 'social capital of war' (Velichko, Tymokhova, & Kudinova, 2022).

Corporate social responsibility, as a rule, embodies the social status and brand of an agrarian company, and during the war it should be considered as an inseparable component of a business entity that wants to continue working in Ukraine. In addition, issues about values also concern potential employees when choosing an employer, as well as the local community when interacting with an agricultural company. In addition to the obvious advantages for the company and the brand, CSR in wartime also acquires a new meaning directly for the employees of the agricultural company. First of all, trust in one's own company and its socially responsible position gives employees and local communities a sense of stability and confidence in the future war' (Velichko, Tymokhova, & Kudinova, 2022).

The activity of Ukrainian enterprises and international companies in Ukraine is an example for the entire corporate world in the implementation of the goals of sustainable development and commitment to humanitarian values.

## Conclusions

- 1. Many economic experts believe that one of the main factors, due to which the national economy of Ukraine withstood the powerful beginning of the full-scale military invasion of Russia, and has been courageously holding on for more than two years, is the high level of social initiatives of business and the self-awareness of Ukrainian society. Agricultural companies not only protect their business, but also continue to work to support the army, their workers, communities and vulnerable populations. During the two years of the war, the national economy adapted to the harsh conditions of wartime, and agricultural companies that did not stop their business in Ukraine with the beginning of a full-scale invasion are interested in their business developing further.
- 2. Today we must admit that the plans of the Russian invaders to paralyze the domestic economy in the first days of the war and bring the vast majority of Ukrainians to the brink of survival and starvation were not realized. Big business not only survived and reduced social programs, but also expanded them; in the conditions of war, it reached a new level of implementation of the principles and

values of corporate social responsibility.

- 3. Proactive activities of agricultural companies in the field of CSR; innovation and digitalization; support for the Armed Forces of Ukraine; two-way transparent communication on activities,; providing financial, psychological and moral support to employees; corporate volunteering in relation to the regions of residence; solving complex environmental problems caused by military actions are the future of ethics, culture and strategy for the development of social responsibility of Ukrainian agricultural business.
- 4. The participants of the survey did not develop a common position regarding which type of activity is more socially responsible and significant in the conditions of war. Some respondents have strengthened established personnel practices and are attempting to maintain them during a military Other agricultural companies crisis. are increasingly concerned about the country's defence problems; their practices have a patriotic orientation. At the same time, all interviewed respondents stated that the agricultural companies they represent work for the victory of Ukraine and the maximum preservation of human potential.

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## RAINWATER DISCHARGE FROM GREEN ROOFS AT NATURAL CONDITIONS

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## Abstract

Newly constructed buildings are subject to stricter requirements - the building must not harm the environment, they must be energetically and economically efficient, comfortable, ecological, etc. One such green energy-saving idea is green roofs and walls of buildings. The purpose of this study is to determine the dynamics of rainwater runoff under real natural conditions, in a typical green roof construction, compared to runoff from a roof covered with bituminous tiles. The study was conducted in the year 2022-2023 by installing two 1 m<sup>2</sup> stands, which are affected by real climatic conditions. One stand was covered with traditional bituminous tiles, but the other was covered with a 'green roof' coating. Meteorological data were obtained from the Kaunas City meteorological station. During the first months of observation, it was possible to record the tendency that rainwater runoff is slow in the case of a green roof, but it continues even after the intense rain has ended. Analyzing the data, it was found during the research that the regression coefficients are very small in assessing the relationship between average daily temperatures and runoff in individual months, R2 - 0.0453 to 0.0553. The study showed that under certain meteorological conditions, a green roof can accumulate up to 35-45 percent more water than a roof covered with bituminous tiles. This means that the water is accumulated and then slowly drains into the rain collection systems.

Keywords: rainwater, green roof, precipitation, water collection.

## Introduction

The extensive green roofs offer a multifaceted approach to stormwater management in cold and wet climates, providing benefits for both the environment and urban infrastructure (Abass et al., 2020). As cities continue to grapple with the challenges of climate change and urbanization, green roofs are likely to remain a valuable tool for sustainable water management strategies (Johannessen, Hanslin, & Muthanna, 2017). A small amount of field research data can be found for different users in northern regions, where frost and snow cover have different influences on construction. While there has been significant research and documentation on green roof technology for stormwater management in various climates, including wet and cold regions, it is true that gaps in knowledge still exist regarding their specific functions and potential use in these environments. Mentens, Raes, & Hermy (2013) conducted a comprehensive review of contemporary literature sources and conducted a reanalysis of collected data to develop an empirical model. The study encompassed data retrieved from 18 relevant publications, comprising a total of 628 records. These records were meticulously scrutinized to extract pertinent information regarding roof properties, precipitation patterns, and runoff characteristics. Through rigorous analysis, the findings unequivocally underscored the predominant influence of roof type on runoff dynamics. Moreover, statistical analyses revealed significant correlations (p<0.05) between annual precipitation levels, roof type, number of layers, and substrate layer depth, with the annual runoff volume. Conversely, factors such as green roof age, slope angle, and roof length exhibited no statistically significant correlations (p>0.05) with annual runoff. Notably, for non-greened roofs, runoff was found to be exclusively dictated by precipitation levels. These

findings elucidate key determinants governing runoff behavior and highlight the multifaceted interplay of factors shaping stormwater management efficacy in built environments.

Alfredo, Montalto, & Goldstein (2010) undertook a rigorous simulation study to analyze the hydrologic performance of green roofs across diverse precipitation scenarios. Their investigation illuminated the escalating urbanization pressures, prompting both regulators and developers to seek innovative green infrastructure solutions and low-impact development technologies. These initiatives aim to judiciously assimilate built infrastructure within the broader landscape while mitigating adverse environmental impacts and enhancing urban resilience.

Such characteristics of the green roof allow for the reduction of rainwater peaks and the removal of momentary loads from the urban rainwater drainage system (Forouzani & Karami, 2011).

Studies confirm that the accumulated moisture is evaporated back into the atmosphere (Blank *et al.*, 2013). The important thing is that the pollutants that were in the rainwater remain in the soil. As a result, not only does the microclimate of the environment improve (due to higher air humidity), but at the same time the cleanliness of groundwater is maintained (pollutants no longer penetrate to them through the soil) (European Commission, 2023).

The amount of water collected and evaporated on a green roof depends on three things:

- types of plants growing on the roof (moss accumulates moisture better than ordinary grass);
- the depth of the substrate (extensiveness/ intensity of planting);
- the type of substrate (Mentens, Raes, & Hermy, 2006).

Germany has emerged as a pioneer in the installation of green roofs in Europe, with over  $25,000,000 \text{ m}^2$  of

green roofs installed in 2000-2001. The growing popularity of green roofs has led to stricter installation requirements, which contribute to mitigating the impact of local floods during the rainy season (Cascone et al., 2018). Furthermore, the absorption of moisture by green roof coverings reduces the burden on the sewage network and the separated rainwater system (Mentens, Raes, & Hermy, 2006). Since the green roof covers and absorbs part of the moisture in its structural elements, there is less load on the general sewage network and the separated rain drainage system. The soil layer of green roofs acts as a filter it cleans nitrogen pollutants from the rain and neutralizes the acid rainwater that has run off. The authors also suggest future research on the influence of various filter materials, such as zeolites, on improving the quality of this water treatment (Wong et al., 2003). The thermal insulation efficiency of green roofs was studied by researchers at Nottingham, Trent University (Wong et al., 2003). Research has shown that with an average daily temperature of 18.4°C, the temperature of the shelter on an ungreened roof reaches 32°C, but on a greened roof it reaches 17.1°C. And this is almost twice as low the temperature (Wong et al., 2003).

Typically, beneath the substrate layer of green roofs, a series of additional strata are commonly installed, including a filter layer, drainage layer, anti-root barrier, and waterproof membrane. The selection and configuration of these layers are contingent upon the prevailing climatic conditions of the installation site. In certain climates, the implementation of an irrigation system may be deemed essential to safeguard the viability and sustenance of vegetation atop the green roof structure. Such measures are crucial for optimizing plant health and promoting ecological resilience within the urban environment (Besir & Cuce, 2018).

The green building walls support a healthier microclimate in the building environment. Plants release oxygen and clean the air we breathe. They reduce the concentration of heavy metals, solid particles, dust, and volatile organic compounds in the air (Shafique, Kim, & Rafiq, 2018). It was established that  $1.5 \text{ m}^2$  of uncut grass produces the annual amount of oxygen consumed by humans. A properly installed green roof allows the building to 'breathe' (Sajedeh Sadat, Hilmi Mahmud, & Muhammad Aqeel Ashraf, 2015).

The purpose of this study is to determine the dynamics of rainwater runoff under real natural conditions, in a typical green roof structure compared to runoff from a roof covered with bituminous tiles.

## **Materials and Methods**

The research was carried out between 2021 and 2022, using two 1-square-meter stands to observe natural conditions. One stand was covered with bituminous tiles while the other had a green roof composed of an insulating film, a water retention membrane, and a layer of perennial grasses. These stands were set up in the courtyard of the Water Research Laboratory of the Kaunas Forestry and Environmental Engineering

University of Applied Sciences. They were equipped with a rain gauge and soil thermometer and had a 15degree slope. All runoff water was collected by catch channels, led to containers, and measured regularly at five-day intervals. Meteorological data was sourced from the Kaunas hydro-meteorological station, and the observation period lasted from 09/15/2021 to 03/15/2022. The data was analyzed using the MS Excel program. Regarding the subject being investigated, the foundation that supported the watercollecting tray was constructed using waterproof plywood. 'Figure 1' shows a cross-section of a green roof from the example presented in GSA.US (2011). To avoid any water leakage during intense rainfall, the simulated rooftop featured a molded barrier encircling its periphery.



Figure 1. Single course extensive green roof experimental plot cross-section.

The roofing component was coated with bitumen, as depicted in 'Figure 2'.



Figure 2. The rainwater harvesting system from the roof with bituminous tiles.

During the case study, plastic containers were used to collect surface water from rain and snowmelt after the roof collection system, under the downpipe installation principle. The amount of leakage was measured in liters. Additionally, meteorological data was gathered via a rain gauge and soil thermometer situated on a green roof stand. This data was supplemented by information from the Kaunas City Meteorological Station (LHMT), accessed online. As there were no variations detected between meteorological readings throughout the observation period, data from the station was utilized.

## **Results and Discussion**

A summary of meteorological data and runoff from the experimental stands is presented in the form of processed graphs in 'Figure 3'.



Figure 3. Schedule of summarized meteorological data for October (2021, 10-31).

During October, there was no leakage recorded in the covered stands between October 1st and 20th, due to very low rainfall. However, runoff from the bituminous roof was observed on October 25th and 30th. In total, only 29.8 mm of precipitation fell throughout the month, with 3.5 mm recorded in the first decade, 10.9 mm in the second, and 15.4 mm in the third. At the stand with a green cover, 13 liters of drainage were recorded for the whole month, while 12 liters were recorded from the green roof. During the first few months of observation, it was noticed that rainwater runoff from the green roof is slower than that of bituminous roofs, but it continues even after the intense rain has ended. This confirms the claims of foreign authors that green roofs accumulate and retain rainwater, thus reducing the runoff peak during rain.

In November, the first minus temperatures were recorded, with -2.2 °C on November 9th and -4 °C and -5°C on November 22nd and 23rd respectively. On November 30th, the temperature was fixed at 8.9 °C, resulting in an average daily temperature of 4.2 °C for the month. A total of 58.5 mm of precipitation fell during November, with 12.6 mm in the first ten days, 9.4 mm in the second, and 36.5 mm in the third. The runoff from the bituminous roof was 31.8 liters, but from the green roof, it was 40.3 liters.

In December, only 9 out of 30 days had fixed plus temperatures. The coldest day was December 15th, with a temperature of -15.6°C. The view of frozen experimental plots is presented in 'Figure 4'.

During this period, frost prevailed at night, and precipitation fell in the form of mixed precipitation during the night and day. In the first ten days, 15.9 mm of precipitation fell, followed by 12.4 mm in the

second ten days and 9.5 mm in the third. The mixed precipitation runoff from the roof covered with bituminous tiles amounted to 2 liters, while from the green roof, it was fixed to 4 liters.



Figure 4. The view of frozen experimental plots in December.

The dynamics of meteorological phenomena in December are presented in 'Figure 5'.



Figure 5. Schedule of summarized meteorological data for December (2021, 01-31).

There were no active observations in January, but the meteorological station provided data. From these data, it can be seen that the average daily temperature for the first ten days was  $-0.8^{\circ}$ C, for the second decade  $-0.3^{\circ}$ C, and for the third  $-0.4^{\circ}$ C. During January, 69 mm of precipitation fell: in the first decade - 28 mm, in the second decade - 10.5 mm, and the third - 29.7 mm. Snow thickness varied between 1-3 cm and reached 5 cm on January 31. Only total runoff from the experimental stands was recorded this month. The runoff from the roof covered with bituminous tiles was 27 liters, whereas the runoff from the green roof was 35.8 liters.

Similar temperature trends were recorded in February, but February was distinguished by a very abundant runoff from the green roof stand. During the month, 60.6 liters of leakage was recorded, and from the roof with bituminous tiles, it amounted to 27 liters, almost half as much. Due to the manual measurement of the mechanical leakage even twice on days 15 and 20, the container used did not contain all the leakage. Therefore, a larger 20-liter vessel was added later that showed 16.9 liters of leakage by February 25. This month has shown that green roofs are excellent at accumulating mixed precipitation, and snowmelt water, and giving it to the drain during the day in plus temperatures and sunshine.

The month of March did not differ in terms of runoff, because during the whole month, only 3 liters of water escaped from the roof covered with bitumen and 9 liters from the green roof. This leak was recorded on March 5. Later until March 15, the drain was not fixed, and the vessels were empty.

Analyzing the data during the winter research, it was found that the regression coefficient is very low when assessing the relationship between average daily temperatures and runoff.  $R^2$  equals 0.0453. The regression coefficient between average daily temperatures and runoff in individual months is presented in 'Figure 6'.



Figure 6. Regression coefficient between average daily temperatures and runoff in individual months.

Such weak dependencies between the two phenomena may be due to inadequate data collection. Runoff was recorded every 5 days, and daily average temperatures were recorded every day. This dependence was tested only between the roof covered with bituminous tiles and the average temperatures in February, and they were negative. This experiment showed that green roof research should be continued for at least several growing seasons to determine the amount of accumulated water and support for urban rain drainage systems and more stands with different layer thicknesses should be installed. Another aspect that emerged only because the low ambient temperatures were observed is the cooling of the structure, which is impossible if the green roof covering was formed as part of the residential building. We believe that this also distorts the results of the study. Our research confirmed the research of many authors that the climate is one of the main factors determining the effective work of this structure.

Green roofs offer various environmental benefits such as improved storm-water management, regulation of building temperatures, reduction of urban heat-island effects, and increased urban wildlife habitat (Oberndorfer *et al.*, 2007). Green roofs, while beneficial, have notable disadvantages. High initial costs stem from installation expenses, materials, and specialized potential structural reinforcements needed to support additional weight. Maintenance, involving watering, weeding, and fertilizing, often requires professional services, increasing long-term costs. Waterproofing and drainage issues can cause leaks and waterlogging, leading to root damage if improperly handled. The structural load of green roofs varies seasonally, stressing building frameworks and potentially necessitating costly reinforcements. Installation is complex, requiring specialized skills and more time than conventional roofs. Plant selection is limited by local climate conditions, and maintaining plant health can be challenging. Green roofs can attract pests, adding to maintenance concerns. Insurance premiums may be higher due to perceived risks, and compliance with local building codes can complicate installation. Although green roofs can enhance energy efficiency, their performance varies, and the energy savings may not always justify the costs (Clark, Adriaens, & Talbot, 2008).

The integration of green roofs with certain architectural styles can be challenging due to compatibility issues with different building designs. This challenge highlights the importance of meticulous planning, precise installation, and consistent maintenance to ensure the long-term success of green roof projects (Thuring, Berghage, & Beattie, 2010). Green roofs offer various environmental benefits but also present drawbacks such as high initial costs, demanding maintenance requirements, waterproofing and drainage issues, structural load concerns, and complexities in installation and plant selection (Peng & Jim, 2013).

To determine the appropriate size for a green roof prototype, it is essential to consider various factors such as stormwater retention capacity, thermal performance, and environmental benefits. Research by Silva *et al.* (2019) assessed the retention capacity of an experimental green roof prototype, indicating a retention rate of 68% to 82% for specific rainfall amounts.

The above conditions shall be taken into account when planning the construction of green roofs and further research shall be carried out prior to the commencement of the design work.

## Conclusions

- 1. During the study, it was found that a green roof has the potential to reduce the load on rainwater systems and retain precipitation in roof layers. The research also observed that rainwater runoff is slow in the case of a green roof, and it continues even after the intense rain has ended. This confirms the claims of foreign authors that green roofs accumulate, retain rainwater, and reduce the runoff peak during rain.
- 2. However, the study also found that there was a weak correlation between average daily temperatures and runoff in individual months. This could be due to improper data collection. Some authors only record the water retention coefficient of green roofs, which is done under laboratory

conditions where the exact amount of water is known to have entered and left the green roof.

3. Under certain meteorological conditions, a green roof can accumulate up to 35-45% more water than a roof covered with bituminous tiles. This means the water is accumulated and slowly drained into

the rain collection systems.

4. The study also recorded that cloudy water runs from the green roof during the first few months of observation. This confirms scientific research that soil particles are removed from the flooded soil layer with the first rainfall, and water erosion occurs.

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## INTEGRATION OF MODULE OF NITRIFICATION IN SOIL ACTIVE LAYER IN THE CONCEPTUAL HYDROLOGICAL MODEL METQ

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## Abstract

In the world, hydrological models are often used in the modeling of ecological components. In the context of the Paris Agreement and the European Green Deal, it is necessary to develop GHG emission modeling capabilities. The development and refinement of the conceptual model METQ is necessary not only for the quantitative analysis of flow, but in addition to its refinement, it is possible to conduct interdisciplinary research in the subfield of ecohydrology, which studies the interaction of water and ecosystems, and in environmental engineering, which addresses the issues of reducing diffuse pollution and reducing greenhouse gas emissions, technology implementation issues, where water content in the soil and groundwater fluctuations play one of the main roles, for example, in the processes of the formation of nitrous oxide emissions. This paper examines potential GHG emission calculation algorithms used to successfully model GHG emissions from soils, with a particular focus on agricultural soils, which contribute one of the largest amounts of GHG emissions in national emission reports for the agricultural sector. Available algorithms for nitrous oxide nitrification calculations are reviewed and possible algorithms that can be used for modeling emissions from soils and integrated into the conceptual hydrological model METQ are discussed. The developed conceptual solutions for modeling GHG emissions from soils will develop a modeling tool that will be used to estimate the volumes of GHG emissions and evaluate the effectiveness of various GHG emission reduction measures, as well as to perform a complex assessment of the soil GHG balance.

Key words: GHG gases, nitrous oxide, hydrological model METQ.

## Introduction

GHG emissions from soil are mainly made up of three gases: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). CO<sub>2</sub> fluxes can be divided into three main stages: soil respiration, which includes respiration by roots, anaerobic and aerobic microorganisms (Hanson et al., 2000), respiration of the ecosystem, which also includes the respiration of the above-ground part of plants; ecosystem gas exchange, which is the balance of CO<sub>2</sub> used in photosynthesis and CO<sub>2</sub> released in respiration. Under anaerobic conditions, methane CH<sub>4</sub> is synthesized in the process of methanogenesis, while methane CH<sub>4</sub> is consumed under aerobic conditions. where oxygen and CH<sub>4</sub> are used in the metabolic processes of microorganisms (Dutaur & Verchot, 2007). Nitrous oxide (N<sub>2</sub>O) and nitric oxide (NO) emissions arise primarily from two fundamental processes: nitrification and denitrification. Nitrification involves the oxidation of ammonium  $(NH_4^+)$  to nitrate  $(NO_3^-)$ via nitrite (NO<sub>2</sub><sup>-</sup>), while denitrification entails the reduction of nitrate (NO<sub>3</sub><sup>-</sup>) to N<sub>2</sub>O and ultimately to nitrogen gas (N<sub>2</sub>). Notably, N<sub>2</sub>O production predominantly occurs during the denitrification process, particularly under anaerobic conditions where micro-scale anaerobic zones are fostered, typically occurring when soil pore filling with water exceeds 50% (Ussiri & Lal, 2012). Nitrification is conventionally conceptualized as a first-order process with respect to soil ammonium (NH<sub>4</sub><sup>+</sup>) concentration under aerobic conditions. Furthermore, the production of N<sub>2</sub>O during nitrification is typically modeled as a fraction of the overall nitrification rate, reflecting the intricate interplay between microbial activity and environmental factors influencing nitrogen cycling dynamics.

Microbial activity, root respiration, chemical processes involved in the degradation of organic

matter, and heterotrophic respiration from soil fauna and mycelia collectively contribute to greenhouse gas (GHG) emissions within soil ecosystems (Chapuislardy et al., 2007). The emission rates of these GHGs are intricately influenced by a multitude of environmental factors, including soil moisture, temperature, nutrient availability, and pH levels (Ludwig et al., 2001), as well as the physical characteristics of both vegetation and soil. Consequently, meteorological parameters, climatic conditions, and agricultural soil management practices exert significant influences on GHG emissions. These factors can be further categorized into direct and indirect influences, elucidating the complex interplay between biotic and abiotic components in regulating soil GHG dynamics (Robertson, 1989).

Given the fragmented and sporadic nature of greenhouse gas (GHG) emission measurements from agricultural soils, there is a critical imperative to employ modeling techniques to regionalize such data and compute global GHG emission budgets. In addition to empirical models (Freibauer & 2003), process-based Kaltschmitt, models incorporating fundamental physical and chemical principles are extensively utilized to synthesize acquired field data (Pattey et al., 2007). These modeling approaches facilitate the integration of diverse datasets, enabling analyses across varying spatial scales, ranging from local to global domains (Reimann et al., 2009). Such modeling endeavors play a pivotal role in advancing our understanding of soil GHG dynamics and informing policy decisions aimed at mitigating anthropogenic contributions to climate change.

Daily organic matter decomposition, nitrification, denitrification, ammonia volatilization, CO<sub>2</sub> emissions (including those from soil microorganisms and root

respiration), plant nitrogen consumption, and plant growth can be effectively modeled, as demonstrated by Li et al. (1994). These models serve as valuable tools for calculating greenhouse gas (GHG) emissions from soil, particularly in agricultural contexts, as evidenced by studies such as those conducted by Abdalla et al. (2011, 2020), Gu et al. (2014), and Li et al. (2012). Input parameters for these models encompass a spectrum of meteorological and soil attributes (e.g., soil structure, pH-value, mass density, organic carbon), alongside factors related to vegetation type and management practices (e.g., tillage, fertilizer application, grain yield) (Abdalla et al., 2009). By assimilating such comprehensive datasets, these models facilitate a nuanced understanding of soil GHG dynamics and offer insights crucial for informing sustainable land management strategies.

To understand the complex nature of the N<sub>2</sub>O calculation algorithm, it is necessary to understand the main components of the nitrogen cycle, where atmospheric N<sub>2</sub> is reduced to NH<sub>3</sub> through biological or industrial nitrogen fixation, which provides nitrogen fertilizer for plants. However, only 30-50% of the nitrogen used in field fertilization and available in the process of decomposing organic matter, which is in the form of NH<sub>3</sub> and NO<sub>3</sub><sup>-</sup>, is used in plant growth processes, while the remaining part is metabolized by soil microorganisms, which has an adverse effect on the environment and climate. The first of these processes, nitrification, refers to the biological oxidation of NH<sub>3</sub>, NO<sub>2</sub><sup>-</sup> and NO<sub>3</sub><sup>-</sup>, which has a high level of immobilization and, under certain conditions, leaches these compounds from the soil, thereby contributing to eutrophication. In the second process of denitrification, NO<sub>2</sub><sup>-</sup> and NO<sub>3</sub><sup>-</sup> is gradually reduced to N<sub>2</sub>O and N<sub>2</sub>. Significant volumes of N<sub>2</sub>O produced by this process enter the atmosphere, contributing to climate change and ozone depletion (Lehnert *et al.*, 2018).

The conceptual hydrological model METQ has been created under the guidance of scientists from the Latvian University of Life Sciences and Technologies and approved for qualitative assessment of flows. The deep integration of the agricultural sector into natural processes requires additional knowledge and opportunities to predict GHG emissions from soil changes under different management scenarios in different soils and in different climatic conditions. This need can be fulfilled using modeling tools. Studying the past experience in the development of tools for calculating GHG emissions, it can be concluded that the models have been developed for different purposes (Colomb *et al.*, 2012). Colomb *et al.* in 2012, one of the first classifications of GHG calculators was created, based on the model use approach 'Figure 1'.



Figure 1. Classification of GHG emission modeling tools.

The development and refinement of the conceptual model METQ is necessary not only for the quantitative analysis of flow, but in addition to its refinement, it is possible to carry out interdisciplinary research in the sub-field of eco-hydrology, which studies the interaction of water and ecosystems, and in environmental engineering, which deals with the reduction of diffuse pollution and greenhouse gases issues of implementing emission-reducing technologies, where soil water content and groundwater fluctuations play one of the main roles, for example, in the processes of the formation of nitrous oxide emissions.

## **Materials and Methods**

The structure of the conceptual hydrological model METQ and the possibilities of integration of GHG

emission calculation algorithms are evaluated from the prism of conceptuality and four main stages necessary for the successful integration of the GHG emission calculation module into the conceptual hydrological model METQ 'Figure 2' are identified.

In the first stage, it is necessary to evaluate the possibilities of selecting data sets necessary for GHG emission modeling from the intermediate results of the conceptual hydrological model METQ, as well as the need for additional parameters and data rows for GHG emission modeling.

In the second stage, existing algorithms of the conceptual hydrological model METQ should be evaluated and a conceptual solution for the integration of GHG emission modules or the creation of additional algorithms should be created.



Figure 2. Possibilities of using the conceptual hydrological model METQ in modeling GHG emissions.

In the third stage, a calculation algorithm is created for each GHG gas, which uses the intermediate results of the calculations of the soil active layer of the conceptual hydrological model METQ and additional parameters related to the calculation of GHG emissions. The fourth step is a long-term measure, where gas measurements in field conditions are used in the calibration of the established GHG emission calculation modules. This study will describe the first two steps and describe the conceptual solution for module integration.

The GHG calculation modules should be divided into two groups, the first group of modules is emissions from the soil, where the GHG calculation modules can be connected to the METQ calculation algorithms of the conceptual hydrological model. GHG calculation modules must be created for carbonic acid gas, methane and nitrous oxide separately 'Figure 3'.



Figure 3. Design model for integration of modules for the calculation of carbon dioxide, methane and nitrous oxide emissions in METQ.

The second group of emission calculation modules is indirect  $N_2O$  emissions and methane emissions from water bodies, where it is possible to connect the GHG

calculation algorithm to the calculation algorithm 'Figure 4' of the total drainage of the conceptual hydrological model METQ.



Figure 4. Design model for integration of modules for calculating indirect nitrogen oxide emissions in METQ.

By analyzing information from available statistical databases and the results of scientific studies, it is currently possible to create an N<sub>2</sub>O calculation module using existing agricultural drainage monitoring data reflecting farm Management practice and calculate indirect N<sub>2</sub>O emissions for the calculation algorithm of components of the conceptual hydrological model METQ drainage.

## **Results and Discussion**

The design platform of THE conceptual hydrologic model METQ allows the use of intermediate results of model calculations such as end-of-day groundwater level, capillary take-off, total evaporation, etc. required in GHG emission calculation algorithms.

The METQ algorithms of the conceptual hydrological model are well documented and allow the integration of GHG emission calculation modules for the calculation of carbon dioxide, methane and nitrous oxide emissions from soil. However, it is necessary to create additional parameter input options for each GHG emission from soil calculation module.

Integration of the GHG calculation into the conceptual hydrological model METQ requires the reprogramming of the existing modelling platform and

the creation of an open platform for the addition of new calculation modules. For GHG modelling from agricultural soils based on nitrification and denitrification processes in soil as well as indirect GHG modelling from watercourses based on nitrogen leakage and nitrification and denitrification processes in water.

The connection between nitrous oxide calculation algorithms and conceptual hydrological model METQ is presented in 'Figure 5'.

Falloon & Smith (2012) expanded the repertoire of models available for simulating carbon (C) and nitrogen (N) emissions from soil. Meanwhile, Butterbach-Bahl et al. (2004) conducted comparative analyses between model predictions and field and measurements across agricultural forest ecosystems. Their findings suggest that while modeling approaches generally yield higher quality estimates, discrepancies between model outputs and empirical data may manifest at both micro and macro scales. Nonetheless, according to these studies, the mean error associated with soil emissions is typically low (Butterbach-Bahl et al., 2004; Hastings et al., 2010), instilling confidence in the utility of modeling data for various applications.



Figure 5. The GHG module connection to conceptual hydrological model METQ and farm management data.

## Conclusions

- In the modeling of hydrological processes, several hundred models are actively used, which can be divided into two main groups, conceptual and physical. The use of conceptual models gives more accurate results for catchments with an area of more than 5 km<sup>2</sup>. Newly built modeling tools are used in the modeling of GHG emissions, but hydrological models with an additional algorithm are successfully used, which allows for the modeling of gas emissions and stands out with greater accuracy in the modeling of nitrous oxide in the temperate climate zone, where soil freezing is observed in the winter period;
- 2. The METQ modeling platform of the conceptual hydrological model allows you to save and use in

#### References

s, but reprogramming the existing modeling platform and orithm creating an open platform for adding new r the calculation modules. For GHG modeling from agricultural soils, where the calculation is based on oxide nitrification and denitrification processes in plants,

emissions calculation algorithms;

as well as indirect GHG modeling from watercourses, where nitrogen leaks and nitrification and denitrification processes in water are taken as a basis.

the calculation algorithm the intermediate results

of the model calculations, such as the groundwater level at the end of the day, capillary rise, total

evaporation, etc., which are needed in the GHG

conceptual hydrological model METQ requires

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## TRANSITION FINANCING IN AGRICULTURE: BALTIC COUNTRY CASE STUDY

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## Abstract

The sector of agriculture is one of the most crucial in the context of ensuring food security as well as in the care for sustainable development. The food security can be improved through several aspects, one of them being the agriculture system transition, implementing more and more regenerative measures. From the agriculture transition, due to the efforts needed to achieve the expected level of green transition, farmers themselves are expected to benefit less than the future society and nature in a whole. Yet both financial institutions and agriculture companies have not reached a common understanding, what requirements should be in place to establish mutually beneficial financial products to achieve the expected level of transition in a timely manner. The aim of this study is to evaluate funding options for agriculture transition in Baltic countries – Latvia, Lithuania, and Estonia. In total, for screening purposes, 29 different Banks operating in the Baltics were identified. The analysis of the financial product purposes provides a high-level perception, that loans, even if not indicating signs of support for green transition, may still support the improvements of overall country and society sustainability. The expert judgement was used to find potential links with the United Nations Sustainable Development Goals (UN SDGs) identifying the potential SDGs that could be tackled when providing the financing to the specific purpose. Only two banks are observed to provide financial products that can be assessed as focused on green transition, and this research shows that financial products for agriculture companies willing to transition to sustainability are not broadly available.

Key words: agriculture transition, sustainable financing, transition financing.

## Introduction

With global trends for greenhouse gas emission (GHG) reduction, enforced by global targets like Paris Agreement, the GHG reduction is expected to be cascaded further across countries and sectors. In the European Union (EU), European Council has enforced a Climate Law within European Green Deal, providing a binding GHG emission reduction target to each member state (European Commission, 2019; European Parliament; European Comission, 2021).

To steer the sector of finance towards a greener and Paris aligned operations, European Central Bank (ECB) in 2020 published an ECB Guide on climate related and environmental risks (ECB, 2020), expecting banks to evaluate and implement measures focused on building banks' credit portfolios to be more resilient to potential climate and environmental risk materialization through their clients (ECB, 2020).

The sector of agriculture is one of the most crucial in the context of ensuring food security as well as in the care for sustainable development (Giller, Hijbeek, Andersson, & Sumberg, 2021). The food security can be improved through several aspects, one of them being agriculture system transition, implementing more and more regenerative measures (Bosma, Hendriks, & Appel, 2022). From the agriculture transition, due to the efforts needed to achieve expected level of green transition, farmers themselves are expected to benefit less than the future society and nature in whole (Bosma, Hendriks, & Appel, 2022; Reidsma et al., 2023). It is recognized that the government-steered transition of large-scale agriculture system to sustainable and environmentally friendly practices, such as regenerative agriculture, cannot happen without private funding when scaled down on a company level transition (Green Finance Institute, 2023) as such a transition requires increased farmer knowledge, changes in used inputs, time dedicated to implement transition measures and building resilience, and even the use of herbicides until a field-appropriate level of cover crop use is found by farmer (Bosma, Hendriks, & Appel, 2022; Mapanje *et al.*, 2023). Yet both financial institutions and agriculture companies have not reached a common understanding on what requirements should be in place to establish mutually beneficial financial products to achieve the expected level of transition in a timely manner (Green Finance Institute, 2023).

There have been several financial mechanisms offered together with loans from financial institutions to provide benefits to agriculture companies, such as lower interest rate margin or delayed pay-back time (Green Finance Institute, 2023), to help de-risk the transition period from the financial aspect, but even in these cases financial institutions expect agriculture companies to provide outputs on the same level as for conventional agriculture (Howard & Maness, 2022).

Another option to enable agriculture transition with the help of financial institutions would be to create specialized agriculture transition loans through the framework of sustainability-linked loans (SLL) that are specially developed in order to improve companies environmental, social and governance performance (LMA, APLMA, & LSTA, 2019; Orden & Calonje, 2022). In case sustainability-linked loans would be offered to agriculture companies for their business model transitions, farmers with credit institutions can agree on key performance indexes (KPIs) directly linked to the funded project, allowing the agriculture companies to set the KPIs they are confident about, meanwhile fulfilling all SLL requirements. Stemming from the nature of SLLs, this financing tool for agriculture transition more likely would be used in the first phases of agriculture transition, driven by farmers keen on implementing sustainable practices (Bosma, Hendriks, & Appel, 2022).

As the need for green transition in agriculture becomes more crucial, the offers for transition focused funding should start to appear. To build a base knowledge about offered funding options for agriculture transition in Baltic countries – Latvia, Lithuania, and Estonia – authors have gathered and analysed publicly available information about offered private funding possibilities from credit institutions in Baltics as of January 2024 focused on agriculture companies and their transition to low-carbon economy. The aim of this study is to evaluate funding options for agriculture transition in Baltic countries – Latvia, Lithuania, and Estonia.

## **Materials and Methods**

The study was focused on financial institutions in Baltic countries. The list of credit institutions (hereinafter Banks) that are accredited to provide financing was obtained from Bank of Latvia, Bank of Lithuania, and Finance Inspection of Estonia (Finantsinspektsioon, n.d.; Latvijas Banka, 2018; Lietuvos Bankas, 2023).

In total, for screening purposes 29 different Banks operating in Baltics were identified, with a split between counties provided in Table 1. Four of the banks were identified as operating in all three Baltic countries, while three banks were identified as operating both in Latvia and Estonia.

Each bank indicated as operating in any of the Baltic countries were screened for the financial products offered to the banks business customers. The banks that are operating in more than one Baltic country, were screened for products in each of the country it is operating to ensure inclusion of country-specific financial products for agriculture companies if such differences were identified. The screening of the financial products was performed on 18<sup>th</sup> of January and 31<sup>st</sup> of January. Throughout the screening process authors were assessing the offered products through answers on the following questions:

- 1. Does the bank have a financial product focused on agriculture customers?
- 2. What is the focus of the financial product to agriculture customers (what are the main topics of the offered financial product)?
- 3. If financial product focused on agriculture

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customers, is this product focused on company transition?

- 4. Does the product description indicate (also indirectly) that the product could be classified as SLL?
- 5. Are there listed any specific requirements that need to be fulfilled before granting the loan or throughout the period when loan is active?

The obtained data is summarized and quantified. After the screening of the first question, for further analysis from the initial number of 29 banks, 22 were excluded as it was not indicated that the bank provides a financing product dedicated specifically for agriculture companies. In total, 8 financial products of 7 banks were screened further for the questions two to five. Information for the second question was gathered for all financial products. The information about each financial product gathered through the second question is used as an input basis to obtain answers for questions three and four. If through questions three and four any indications, even partial, are gathered that the financial product is or might be focused on transition or the financial product could be classified as SLL or focused on green transition, answers to the fifth question shall be obtained. Only three financial products were screened for the final question. The screening results are represented separately for each Baltic country to cover the full scope of financial product availability for agriculture companies.

The obtained screening results are summarized based on two groups: i) results on available financial products with a focus on green transition or the product that can be classified as SLL and ii) results of focus or theme of the financial product.

The expert judgement was used to find potential links with the United Nations Sustainable Development Goals (UN SDGs) identifying the potential SDGs that could be tackled when providing the financing to the specific purpose.

Five experts from five different fields: banking sector; agricultural sector; science and research sector; food processing sector and local municipality, were involved. For each financial product the SDG were included in the list if at least three experts mentioned this SDG.

Table 1

Country or geographic coverage	Total number of Banks	Number of operating only in this country	Number of banks operating in two Baltic countries	Number of banks operating in three Baltic countries	
Lithuania	13	9	0		
Latvia	14	7	2	4	
Estonia	13	6	3		

Credit institutions operating in Baltic countries

#### **Results and Discussion**

In the study, 29 financial institutions operating in Baltic counties were screened, in total, identifying eight financial products offered by seven financial institutions

focused specifically on agriculture customers. From the identified products none of them were country-specific; therefore, further all identified financial products for agricultural customers were assessed as unique, even if offered in all three Baltic counties, see 'Figure 1'. When screened if the financial product could be dedicated to green transition or if the product could be classified as sustainability linked only three products were identified as showing signs, even partially, of being dedicated to green transition. The availability of specialized financial products for agriculture was found to be three times lower compared to initial list of financial institutions screened for the study. Eight financial products are available in all three Baltic countries with five or six possible agriculture financial products per country. In the Baltics, during the time of the study only two banks were offering in total three financial products for agricultural transition.



Figure 1. Financial product availability for agriculture customers in Baltics.

The country specific split of agriculture financial products focused on green transition and other financial products for agriculture companies is provided in 'Figure 2'. Even more, from these three loans only one financial product requires to provide additional information to financial institution to receive the loan, yet no information in available resources identified if there are requirements in place to report KPIs throughout the period, when loan is active.

The loan purposes, collected from information about financial products in Baltics dedicated to Agriculture customers, indicate that these loans still could tackle issues covered by UN SDGs. The analysis shows that agriculture financial products can be granted for seven different purposes as indicated in 'Figure 3'.





The study identified that the offered financial products potentially could tackle in total thirteen out of seventeen SDGs, even though these links cannot be observed in the product offering (except for financial product for afforestation where clear green transition loan offering is observed). Zhao and Duan (2023) in their research highlight key governmental elements: involvement of the modernization and expansion of the financial system, the revision of national efficiency measures, and the establishment of a technological long-term infrastructure marketplace (Zhao & Duan, 2023).

The results obtained through the study show that although the green transition loans or SLLs in agriculture sector are not broadly accessible at the time the study was conducted, the financial products available for agriculture companies still do tackle the issues regarding transition to green or more sustainable business models and wider improvements regarding sustainability in the society. Further research is needed to analyse the available financial products more thoroughly in order to gain greater understanding of the real coverage of transition financial products. Additional research is needed to investigate the need of agriculture companies for green transition financial products, more concrete transition financial product purpose and what requirements they would like to see in the transition products to enhance the achievement of their set goals through provided financing. The performed study in future can be compared to offered products both at the time the next study is performed as well as the products available at the time of this study performance, to conclude, if the offering of green transition and other financial products for agriculture companies meets the user demand, and what, if any changes, can be observed in the financial product offering to agriculture companies.



Figure 3. Financial product purposes and the SDGs they tackle.

## Conclusions

- 1. The topic of green transition is still relatively new. Although there have been studies performed to understand the principles of SLLs, less research has been performed studying SLLs when financing transition in agriculture.
- 2. About one third of Baltic financial institutions offer specialized financial products for agriculture companies, yet only two banks are observed to provide financial products that can be assessed as focused on green transition, ensuring that financial products for agriculture companies willing to

transition is not broadly available.

- 3. The analysis of the financial product purposes provides a high-level perception that loans, even not indicating signs of support for green transition, may still support the improvements of overall country and society sustainability.
- 4. Further research is needed to understand the demand for green transition needs in agriculture sector, the potential requirements agriculture companies would agree to and compare to the current offering of the green transition and other financial products for agriculture companies.

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## CHANGES IN LITHUANIAN MEADOWS AND NATURAL PASTURE AREAS OVER A 20-YEAR PERIOD AND TRENDS

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## Abstract

In Lithuania, as well as throughout Europe, the areas of natural meadows and pastures are gradually decreasing due to the intensification of agriculture, leading to the plowing of meadows and the consequent loss of valuable biodiversity, a crucial component of the landscape. The problems associated with meadow and pasture reduction is essential for informed decision-making, sustainable land management, the conservation of biodiversity and ecosystem services. Various methods, including comparative, analytical, statistical, and logical analysis, were employed in the investigation. The comparative study employed information from the Land Fund of the Republic of Lithuania covering the period from 2003 to 2023. The article also analyzes the reasons and perspectives of the decrease in meadow and natural pasture areas. In 2023, meadows and natural pastures in the Republic of Lithuania covered 362,351.79 ha, constituting 5.55% of the country's territory. From 2003 to 2023, the total area of meadows and natural pastures decreased by 135,439.55 hectares or 27.21%. From 2003 to 2023, in nine out of ten Lithuanian counties, the areas of meadows and pastures decreased. The most significant loss of these areas occurred in Siauliai County (36,828.33 ha or 59.02%), while the least loss was in Klaipeda County (141.05 ha or 0.34%). The decrease in meadow and natural pasture areas can be attributed to various factors: changes in land use, urbanization, climate change and other influencing factors. The area of meadows and pastures in Lithuania should increase by 87,000 hectares, and meadows and pastures in country would cover an area of 449,351.79 ha or 6.88% of the total area of the Republic of Lithuania. **Key words:** meadows, natural pastures, area change.

### Introduction

The land areas with fertile soil (agricultural land) used for agricultural activities are a limited and not easily replenishable natural resource. The preservation, rational use, and improvement of economic properties are in the public interest (Aleknavičius & Aleknavičius, 2017).

In addition to arable land and gardens, meadows and natural pastures are classified as agricultural land.

Meadows include areas covered with perennial grasses (cultivated meadows, established in peaty soils through a complex of drainage and agrotechnical measures) or naturally grown land areas (natural flooded and dry meadows) that are systematically mowed or can be mowed. Natural pastures include areas covered with natural perennial forage grasses and are used or suitable for grazing animals. Meadows and natural pastures may undergo a process of peat formation (peat meadows and pastures), and they may contain bushes, individual trees, or stones (bushy or stony meadows and pastures). Meadows or natural pastures where more than 70% of the area is covered by shrubs and trees due to overgrowth are classified as marshes (when a meadow or natural pasture is overgrown) or as wooded areas (trees and shrubs when a meadow or natural pasture is overgrown with shrubs) (Nacionaline..., 2023).

Meadow habitats are exceptionally rich in terms of plant species diversity and are associated with various animal species, especially insects.

The preservation of the floristic compositions, individual species, and ecological functions of natural and semi-natural grasslands is crucial. Considering that these biomes are currently among the most endangered in the world (Janssen *et al.*, 2016).

Semi-natural grasslands exhibit high species diversity and offer a broad array of ecosystem services, including

biomass production for livestock grazing and carbon sequestration. The threats of land abandonment and habitat destruction jeopardize these ecosystems, underscoring the importance of restoration efforts in cases of degradation (Durbecq *et al.*, 2023).

Grasslands play a vital role in the whole Earth's system, sustaining a diverse range of fauna and flora. They also offer crucial ecosystem services: including pasture forage, clean water provision, hydrological balance, erosion prevention, pollination support, and sequestration of greenhouse gases (Buisson *et al.*, 2022).

Author Wilsey (2021) believes that grasslands contribute various ecosystem services to society, such as capturing nutrients, producing food, storing carbon, supporting tourism and recreation, and generating nectar and pollen. Culturally, grasslands hold significance as outdoor scientific laboratories.

Grasslands face growing degradation due to changes in land use and disruptions to their natural disturbance patterns, leading to fundamental shifts in their structure and functioning. This degradation heightens the importance of protecting and restoring grasslands. It may also diminish the ability to fully restore characteristics typical of pristine, old-growth grasslands (Buisson *et al.*, 2022).

Grasslands, spanning vast areas, exhibit surprising biodiversity but have been significantly altered by human activities and lack the level of protection afforded to some other biomes. Restoration efforts offer a chance to reverse this degradation and enhance local biodiversity (Wilsey, 2021).

The conversion and degradation of grasslands can happen swiftly. The most harmful disturbances are those that quickly obliterate belowground structures, including activities like land cultivation, mining, and forestation (Bardgett, et al., 2021).

With the United Nations declaring 2021-2030 as the decade of ecosystem restoration, it has become increasingly important to recognize grasslands as vital ecosystems for the preservation and restoration of terrestrial biodiversity and environmental services. Additionally, they play a key role in managing climate change (United Nations..., 2022).

Author Retallack (2013) in his science article states that contemporary agroecosystems like grasslands and pastures, subject to intensive human regulation, have the potential to serve as carbon sinks. Implementing carbon sequestration practices could prove beneficial in mitigating human-induced worldwide warming.

Pastures often have the ability to provide increased ecosystem services, and in certain instances, improve them. Typically resulting in environmental advantages and enhanced overall stability in the context of climate change (Veldkamp *et al.*, 2023).

Studies indicate that pasture systems have the potential to enhance overall productivity across the system while simultaneously offering various ecosystem services (Smith *et al.*, 2022).

The concept of 'managed grazing' is attracting attention for its potential role in mitigating climate change. This is achieved by minimizing bare ground, encouraging perennialization, and thereby improving the sequestration of soil carbon (Gosnell, Charnley, & Stanley, 2020).

The impact of livestock systems on environmental change is a subject of controversy. Pasture-based systems are viewed as a sustainable option because of their adaptation to utilizing local natural resources. Nevertheless, these systems have restricted productivity per unit of product and rely on public economic support in Europe. Moreover, these systems exhibit diversity in both farm structure and resource utilization, factors that can influence their overall sustainability (Muñoz-Ulecia *et al.*, 2023).

Globally, a minimum of one billion people residing in grazing ecosystems rely on these ecosystems for their livelihoods, primarily through livestock production, and for various environmental services crucial to human welfare. To ensure long-term sustainability of rangelands and ecosystem resilience, there is an immediate need for comprehensive agricultural production policies on a global scale. These policies should aim to shift from current detrimental industrial inorganic input agricultural practices to sustainable resource management that promote enhanced environmental function (Teague & Kreuter, 2020).

The object of article is meadows and natural pasture areas of Lithuania.

The purpose of this article is to conduct an analysis of the change in meadows and natural pasture areas over a twenty-year period.

Tasks to be resolved:

- 1. Examine the historical development and present state of meadow and natural pasture areas.
- 2. Investigate the change in meadows and natural pasture areas from 2003 to 2023.

3. Predict trends in the change of meadows and natural pasture areas.

## **Materials and Methods**

Various approaches were employed in the research for this article, encompassing both theoretical and practical methods. In pursuit of the article's objective, a comparative method was utilized to assess the transformation of meadows and natural pasture areas in Lithuania and its ten counties over the period 2003– 2023. The resultant changes are presented in both hectares and percentages. Comparative analysis relied on data from the Land Fund of the Republic of Lithuania (Nacionaline..., 2003–2023) covering the years 2003–2023.

Analytical and logical analysis methods were employed to identify the factors contributing to the decline in meadow and natural pasture areas in Lithuania and its nine counties out of ten. The article highlights the observed trends in the alteration of meadows and natural pasture areas in Lithuania.

To enhance the study's comprehensiveness, a graphical method was also applied.

## **Results and Discussion**

### Historical and current situation overview

Natural meadows and pastures are an integral part of Lithuania's landscape and culture. These ecosystems play a crucial role in nature and in all our lives. By absorbing carbon dioxide from the atmosphere and stabilizing moisture regimes, they are important for many species, including birds and natural plant pollinators, as habitats.

Meadow ecosystems are highly important for biological diversity. Meadows are extraordinarily rich in species, hosting various wild pollinators (bees, wasps, butterflies, ants), beetles, and other invertebrates. Unique, rare, and protected plants also grow in meadows.

In Lithuania, efforts to improve meadows and pastures began in the 16th-17th centuries. Shrubs were cleared, and thickets were destroyed. The development of meadow farming was hindered by wars, plague epidemics, and various natural disasters. Meadows were overgrown with shrubs and forests. In the second half of the 18th century, meadows in the Nemunas Delta started to be drained through ditches and drainage. From the 15th to the mid-19th century, meadows occupied 12–27% of the territory of Lithuania at that time. Perennial grasses were sown in manors, and meadows were fertilized with manure.

More attention to the improvement of meadows and pastures began in the years 1928–1940 when livestock farming was more extensively developed. In 1930, natural meadows covered 13.3%, permanent pastures 8.9%, and fodder grasses 7.5% (all grasslands – about 41% of agricultural land, about 30% of the territory). In 1939–1940, meadows were 14.2%, pastures 9.4%, and fodder grasses 8.9% (about 33% of the country's territory), and in 1951 (respectively) – 11.6%, 7.2%,

## 5.0% (about 24%).

Until 1941, cultivated meadows and pastures (about 50 thousand hectares) during the war and post-war period became waterlogged, overgrown with shrubs, and few fields remained with good grass.

In 1955, efforts were made to improve grassland management – to increase the fertility of grasslands, especially meadows, cultivate natural grasses, and develop grass seed production. Land reclamation specialists comprehensively performed drainage, removal of shrubs and stones, expansion of areas, construction of polders, and other land improvement works until 1992.

The cultivation of cultural grasses increased rapidly.

In 1970, natural meadows and pastures covered about 10.0%, cultural meadows and pastures about 5.4%, perennial grasses about 9.0% (about 24.5% of the territory). In 1980, cultural meadows and pastures covered about 11%, natural meadows about 5.6%, perennial grasses about 8.1% (about 24.7% of the territory). In 1990, meadows covered about 4.6%, pastures about 13.4%, perennial grasses about 9.3% (all grasslands – about 50.7% of agricultural land, about 27.3% of the territory) (Žemaitis, 2024).

In the 8th-9th decade of the 20th century, an average of about 50 thousand hectares of cultural meadows and pastures were annually established and renewed. By 1990, about 90% of all grasslands were cultivated (about 27% of the country's territory).

In the 10th decade of the 20th century, after regaining land, farmers drained many cultural pastures in drier meadows, and perennial grasses were plowed or abandoned.

According to the data of 2023 (Nacionaline..., 2023), meadows and natural pastures in the Republic of Lithuania covered 362,351.79 hectares, constituting 5.55% of the country's territory.

Analyzing the data in hectares, it is evident that in 2023, the largest areas of meadows and natural pastures were in the Vilnius (66,651.02 ha) and Utena (63,584.03 ha) counties. The smallest of these areas were identified in the Marijampole county (17,349.95 ha) (Table 1).

Nevertheless, in the calculation of percentages concerning the county's area, it was observed that Utena (8.84%) and Klaipeda (7.86%) counties have the highest proportion of meadows and natural pastures. In Lithuania, there are nine European Union importance natural meadow habitats, covering an area of 24.22 hectares (steppe meadows (1.60 ha), species-rich pastures and grazed meadows (4.19 ha), fen meadows (1.46 ha), alluvial meadows (4.22 ha), forest meadows (5.71 ha), and others (7.04 ha). Out of the nine European importance meadow habitat types present in Lithuania, the condition of all is unfavorable – either unsuitable or poor (Lietuvos republikos..., 2015).

Lithuania is a country located in the forest zone, which means that without maintaining open habitats, they naturally become overgrown with bushes, eventually forming a forest. Most of the current Lithuanian meadows have formed precisely due to livestock grazing.

Table 1 Meadows and natural pasture areas in hectares and percent in counties of Lithuania Republic in 2023

m 2020				
Counties of	Meadows and natural pasture area			
Lithuania	ha	%		
Alytus	26,979.21	5.00		
Kaunas	33,858.07	4.19		
Klaipeda	41,050.04	7.86		
Marijampole	17,349.95	3.88		
Panevezys	36,693.28	4.66		
Siauliai	25,567.85	2.99		
Taurage	27,576.83	6.26		
Telsiai	23,041.51	5.30		
Utena	63,584.03	8.84		
Vilnius	66,651.02	6.85		

Source: author's calculations based on Nacionaline..., 2023.

Extensive livestock grazing and shepherding over a long period have allowed the creation of particularly valuable meadows, characterized by the abundance of plant and insect species, becoming habitats for birds, reptiles, and other living organisms.

Through extensive grazing, microhabitats and a unique diversity of plant communities are formed; cattle attract many insects, which are then followed by birds. Natural pastures and meadows can serve as carbon storage mechanisms, as plants in these areas absorb and retain carbon from the atmosphere.

The diverse vegetation in meadows and pastures helps control water flow, reducing the potential risk of erosion and contributing to improved water management.

Pastures provide an opportunity for the natural rearing of animals, allowing them to benefit from various types of fodder and obtain proper nutrition, contributing to the sustainability of animal husbandry. Meadows and pastures offer the beauty of nature and a natural environment, which holds aesthetic value and can be utilized for recreation and ecotourism.

Natural pastures can be resilient to climate change and aid in adapting to environmental shifts.

In the European Union's Biodiversity Strategy for 2030 (European Commission, 2020), it is emphasized that areas of high biodiversity value, including natural meadows, should receive special attention.

## *Changes in the areas of meadows and natural pastures in the Republic of Lithuania from 2003 to 2023*

In this article, a study was conducted on the changes in the areas of meadows and natural pastures over a twenty-year period. In 2003, meadows and natural pastures in Lithuania covered an area of 497,791.34 hectares. As seen in the first figure, these areas decreased each year. Over the period from 2003 to 2023, the total area of meadows and natural pastures decreased by 135,439.55 hectares or 27.21%. And in the year 2023, it occupied an area of 362,351.79 'Figure 1'.



Figure 1. Meadows and natural pasture area change in hectares in Lithuania in 2003–2023 (Nacionaline..., 2003–2023).

It is worthwhile to examine how the analyzed areas changed in the country's counties. From 2003 to 2023, in nine out of ten Lithuanian counties, the areas of meadows and pastures decreased, with only Utena County mentioned experiencing an increase in the

#### mentioned area 'Figure 2'.

So, after analyzing the change in the area of meadows and natural pastures over twenty years, it was determined that the most significant loss of these areas occurred in Siauliai County (36,828.33 ha or 59.02%), while the least loss was in Klaipeda County (141.05 ha or 0.34%). As mentioned, only in the Utena County, the studied area increased (1,795.00 ha or 2.91%) (Table 2). Intensive agriculture or urbanization can result in a reduction of meadows, while conversely, sustainable agricultural practices can promote the preservation or even expansion of these areas. The reasons for the decrease in meadow and natural pasture areas in Lithuania and its counties are presented in the following section.

The causes of the decrease in meadows and natural pasture areas can be various and multifactorial.

In Lithuania, the area of meadows is gradually decreasing. This trend is also observed throughout the European Union as there is a shift away from extensive farming towards intensive agriculture, or meadows are abandoned, especially in small and infertile areas with complex terrain.

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Vilnius C	ounty	68934,4	72962,3	78401,5	70646,3	66651,02
Utena Co	unty	61789,03	65678,01	70295,28	61680	63584,03
Telsiai Co	ounty	41321,24	36865,96	33868,08	20366,5	23041,51
Taurage C	County	48470,12	42872,38	38945,72	19193,4	27576,83
Siauliai C	ounty	62396,18	49328	46268,91	30056,86	25567,85
Panevezy:	s County	49463,76	46724,83	46558	32279,34	36693,28
Marijamp	ole County	35379,66	34996,83	34300,32	18911,02	17349,95
■ Klaipeda	County	41191,09	39219,91	38165,93	32132,98	41050,04
Kaunas C	ounty	42285,3	40016,1	36249,15	38700,31	33858,07
Alytus Co	ounty	46560.56	47890.25	52416.39	30434.98	26979.21

Figure 2. Meadows and natural pasture area change in hectares in counties of Lithuania in 2003–2023 (Nacionaline..., 2003–2023).

## Causes and trends of decrease in meadows and natural pasture areas

The European Union influences Lithuania's agriculture through the Common Agricultural Policy (CAP). Changes in CAP can impact land use practices and may encourage or hinder the use of meadows.

In Lithuania, similar to the entire European Union, the areas of natural meadows and pastures are gradually diminishing as agriculture intensifies, leading to the conversion of meadows into arable land. As mentioned, in Lithuania from 2003 to 2023, the area of meadows and natural pastures decreased by 135,439.55 hectares or 27.21%.

Table 2

Meadows and natural pasture area change in hectares and percent in counties in 2003–2023

Counties of	Meadows and natural pasture area			
Lithuania	ha	%		
Alytus	- 19,581.35	- 42.06		
Kaunas	- 8,427.23	- 19.93		
Klaipeda	- 141.05	- 0.34		
Marijampole	- 18,029.71	- 50.96		
Panevezys	- 12,770.48	- 25.82		
Siauliai	- 36,828.33	- 59.02		
Taurage	- 20,893.29	- 43.11		
Telsiai	- 18,279.73	- 44.24		
Utena	+ 1,795.00	+ 2.91		
Vilnius	- 2,283.38	- 3.31		

Source: author's calculations based on Nacionaline..., 2003–2023.

Meanwhile, during the same period, the area of arable land increased by 72,181.59 hectares or 2.46%. Therefore, with the rapid development of intensive agriculture, especially crop farming, farmers are transforming meadows and natural pastures into arable land. These land use changes aim to achieve greater agricultural production and income.

The decrease in meadows and the expansion of cultivated land due to increased use of mineral fertilizers and plant protection products negatively affect the condition of water bodies and intensify soil erosion.

Another reason for the disappearance of meadows and pasture habitats is the decline in rural population and small-scale farmers, resulting in a significant reduction in domestic livestock, which were previously crucial landscape-shaping factors.

Technological progress can also influence changes in meadows and natural pasturelands. New agricultural technologies and methods can alter traditional farming practices, sometimes necessitating a reduction in extensive land areas.

Climate change can affect agricultural conditions, including potential changes in soil moisture or other environmental conditions that may impact meadows and pastures.

Additionally, abandoned meadows are often reclaimed by forests, overgrown with shrubs, or become marshy. Therefore, due to changes in land use, urban development, forestry expansion, natural transformations into wild areas, and other reasons, the areas of meadows and natural pastures in Lithuania decreased during the period from 2003 to 2023.

While in nine out of ten Lithuanian counties, there are trends to decrease meadows and natural pasture areas, there are also initiatives and efforts in these areas to increase or restore these areas. Factors that can contribute to the increase of meadows and natural pasture areas include: 1. Environmental protection and support for biodiversity: Programs and projects aimed at restoring meadows and natural pasture areas may be implemented to preserve biological diversity and environmental stability. This can be crucial from the perspective of natural ecosystems, plant life, and animal diversity.

In the Lithuanian Rural Development Program (Lietuvos kaimo plėtros..., 2023), there is a measure called 'Agrarian Environmental Protection and Climate', which additionally supports several activities aimed at preserving natural meadows.

Additionally, for the past couple of years, a pilot measure 'Conservation of Abundantly Flowering Natural Meadows' has been implemented as part of the LIFE NATURALIT integrated project. Selected farmers participate in this measure, learning to identify key plants indicating the naturalness of meadows on their land. Over the course of several years, the dynamics of meadows will be observed as they are used in the same way as farmers have used them until now. The methodology will be refined, and it is likely that after a few years, it will be included in the Lithuanian Rural Development Program.

- 2. Agricultural policy contributes to the conservation and development of the analyzed areas. In Lithuania, changes in agricultural policy may be implemented to promote or provide support for extensive agriculture, including meadows and natural pastures. Lithuanian farmers can receive support from the European Union under the Lithuanian Rural Development Program 2014-2020.
- 3. Agroecological farming practices are being implemented. Growing interest in agroecological farming systems can promote agricultural activities that emphasize ecosystem balance and natural pastures. Encouraging the country's farmers to contribute to climate change mitigation, effective natural resource management, biodiversity, and the preservation of ecosystems, habitats, and landscapes, the support for the upcoming period is linked to the requirements of Good Agricultural and Environmental Condition (GAEC). One of the requirements is the protection of perennial meadows. GAEC requirements are mandatory for all farmers, and non-compliance may result in the reduction or elimination of direct payments.
- 4. Development of ecotourism. Ecotourism can be promoted as an alternative to traditional agriculture, supporting natural pastures and meadows as tourist attractions. In Lithuania, the European Green Belt project 'Ecotourism Solutions for Small Rural Entrepreneurs in the European Green Belt in Lithuania' is being implemented.

Two methodologies have also been released - one for ecotourism service providers (Lietuvos kaimo turizmo..., 2023) and another offering advice for ecotourists (Lietuvos kaimo turizmo..., 2023a). The development of ecotourism can be beneficial for local economies and community development, as well as environmental conservation. To foster this type of tourism, an integrated approach involving economic, environmental, and ethical processes is necessary, with the engagement of stakeholders.

- 5. Scientific research and education: scientific research on the importance of meadows and natural pastures to ecosystems can influence policy formation, while educational activities can promote understanding of the value of these areas.
- 6. The restoration of meadows and natural pastures. The restoration of meadows and natural pastures is a process aimed at restoring or returning the former condition of meadows and natural pastures. This can be important for preserving biodiversity, environmental sustainability, and the traditional agricultural landscape.

Farmers, when applying for support for agricultural land and other areas, as well as livestock, annually committed not to plow perennial meadows. However, following a demand from the National Payment Agency under the Ministry of Agriculture, they are now required to restore these meadows if the proportion of perennial grassland to the total agricultural land area in Lithuania decreases by more than 5%. Maintaining perennial meadows was one of the three eligibility requirements for farmers from 2015 to 2022, and those who fulfilled this obligation received basic direct and decoupling payments. It is estimated that the area of perennial meadows that farmers will need to restore is about 87,000 hectares, representing 69% of the total plowed area. The restoration of perennial meadows will need to be declared when reporting crop areas in 2024. This obligation applies to farmers who plowed more than 0.5 hectares of perennial meadows between 2020 and 2022. They will need to restore the plowed area with perennial meadows during that period. It is important to note that the restoration of perennial meadows can be done in various ways – it is not necessary to do it in the same area or location. Meadows can be restored in a different location, as long as the restored meadows are maintained and declared for five consecutive years from 2024. Therefore, if farmers fulfill their obligations, the area of meadows and pastures in Lithuania should increase by 87,000 hectares, and meadows and pastures in the country would cover an area of 449,351.79 hectares or 6.88% of the total area of the Republic of Lithuania.

Preservation of meadows is an important action in the pursuit of mitigating climate change: meadows absorb carbon dioxide, preventing a significant decrease in soil organic carbon content. Their preservation contributes to maintaining and protecting biodiversity, including rare and native species and their habitats. Meadows and pastures are crucial elements of cultural landscapes, contributing to landscape aesthetics and identity.

Preserving meadows and natural pastures is a challenge related to sustainable agricultural development, nature conservation, and environmental sustainability. This requires an integrated approach involving both farmers and the public, aiming to balance economic activities with nature conservation.

## Conclusions

- 1. In Lithuania, efforts to improve meadows and pastures began in the 16th-17th centuries. From the 15th to the mid-19th century, meadows occupied 12-27% of the territory of Lithuania. In 1930, approximately 41% of agricultural land and around 30% of the country were occupied by meadows and pastures. In 1970, natural meadows and pastures covered about 10.0%, cultural meadows and pastures about 5.4%. By 1990, 90% of all grasslands had been cultivated, constituting about 27% of the country's territory. In 2023, meadows and natural pastures in the Republic of Lithuania covered 362,351.79 hectares, accounting for 5.55% of the nation's land area. It was noted that Utena County had the highest percentage of meadows and natural pastures at 8.84%, followed by Klaipeda County with 7.86%.
- 2. In Lithuania, from 2003 to 2023, there was a decline of 135,439.55 hectares, equivalent to 27.21%, in the overall area of meadows and natural pastures. It was found that the most substantial reduction in these areas took place in Siauliai County, with a loss of 36,828.33 hectares, accounting for 59.02%. Conversely, Klaipeda County experienced the least decline (141.05 ha or 0.34%). Notably, Utena County was the only county in Lithuania, where the studied area increased by 1,795.00 ha or 2.91%.
- 3. The factors that can contribute to the increase of meadow and natural pasture areas include: support for environmental protection and biodiversity, agricultural policy, agroecological farming practices, development of ecotourism, scientific research and education, and national or international support programs, the restoration of meadows and natural pastures. The meadow and pasture area in Lithuania is expected to grow by 87,000 ha, resulting in a total coverage of 449,351.79 ha or 6.88% of the entire territory of the Republic of Lithuania.

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# THE INFLUENCE OF ACTIVE LEISURE AREAS ON THE VISUAL QUALITY OF THE URBAN ENVIRONMENT



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## Abstract

In planning active leisure areas, the main emphasis is placed on the elements used in the infrastructure of children's playgrounds and recreational sports areas, their functionality, and compliance with various safety requirements in the public outdoor space. However, there are no uniform requirements for the aesthetics of the elements or the visually coherent inclusion of such infrastructure in the surrounding environment and existing infrastructure. The study aims to evaluate the impact of the infrastructure of active leisure areas on the visual quality of the public outdoor space and possible improvements by choosing alternative elements with a different visual design but similar functionality and to distinguish the main characteristic features for determining the visual quality of elements and characterize the impact on the surrounding environment. The research uses the descriptive or monographic method to collect and analyse the elements and functionality included in the surveyed territories in the summer and autumn of 2022, evaluating the aesthetic quality of the elements in active leisure areas in the public outdoor space of Riga and Tallinn. The study's main results reflected several problems related to integrating active recreation areas into the surrounding environment. They highlighted issues related to the quality of the existing environment, which can be described as insufficient or low and which characterizes the planned development as coming into conflict with the existing environment's aesthetic qualities or their absence.

Key words: active leisure areas, recreational sports areas, visual quality.

## Introduction

Active leisure areas in the urban environment provide a functional diversity of activities, which is related to the promotion of the active lifestyle of the population to improve the overall quality of life (State of Victoria, Department of Health and Human Services, 2018; Ayala-Azcárragaa, Diazb, & Zambranoa, 2019; Hillsdon et. al., 2006; Kalniņa & Stokmane, 2022; Janpavle & Īle 2022). A multidimensional approach to urban planning interlinks architecture's visual-spatial dimensions with green structures and the infrastructure necessary to ensure activities create a modern and high-quality urban environment (Īle, 2022; Kalniņa, & Stokmane, 2022). Therefore, integrating active leisure areas in the urban environment is closely related to contemporary trends in architecture and environmental design directions to create a modern and harmonious urban environment at all levels. When planning activity areas, the impact of the infrastructure required for the provision of activities and the elements to be included in improving the visual aesthetic quality of the surrounding area is not always considered, affecting the overall quality of the city on a larger scale.

A high-quality environment for outdoor play is widely discussed, which would be related to the availability of natural objects and structures, the inclusion of natural elements, various materials and shapes, and terrain in the infrastructure of playgrounds (Loebach & Cox, 2022; Talarowski *et al.*, 2019). The need for a high-quality and organized environment is determined, which is related to children's further development and impressions, as well as the environment quality they see around them, which can affect further experience and critical thinking about the perception of qualitative living space in adulthood (Zerlina & Sulaiman, 2020; Loebach & Cox, 2022). What can apply to the opinion of the specialists involved in the planning of active leisure areas and the customer or

developer regarding decisions related to urban design solutions and elements that should be included, their interaction with the surrounding environment, guided by the experience, knowledge, and subjective vision. There are no directly defined visual aesthetic characteristics of the public outdoor space concerning active recreation areas, which should ensure that such improvement generally fits into the surrounding environment. There are more discussions about how a high-quality and natural environment for play can improve the quality of the user experience (Loebach & Cox, 2022; Talarowski *et al.*, 2019), but the components or structures to be included in the improvement are not explicitly listed, which would fully ensure the necessary functionality and how it would be included in the surrounding environment.

The components characterizing the urban environment for visual aesthetic quality are defined in separate studies for parks that include active leisure areas as an essential component of parks and cities that provide accessible activities for all. Components that are associated with aesthetics are more applicable to flora and fauna, water features, art objects, landmarks, sports, and recreation infrastructure - team sports playing fields or cafes, while recreational sports areas and children playgrounds are defined as recreation infrastructure (Zhang *et al.*, 2022). This partially explains the insufficient emphasis that has

This partially explains the insufficient emphasis that has been placed on the visual aesthetic quality of active leisure areas, as they are primarily designed to provide the necessary functionality but are not evaluated as part of the overall improvement as a visual aesthetic component that complements or highlights the overall image of the surrounding environment. A study on innovative children playgrounds (Talarowski *et al.*, 2019) highlights the components that should be included in them - different surface covering materials, natural areas for play with plants, undefined elements that do not directly define the functions of play, moving or movable elements, various non-traditional play elements, inclusive design for all age groups, but it is not mentioned how such elements should look visually or fit into the surrounding environment with the main emphasis on natural elements and materials. Similar to the elements included in recreational sports areas, the main emphasis is placed on their functionality. Still, regarding visual quality, the user experience, visual perceptibility of the element, and resistance to vandalism are mentioned (State of Victoria, Department of Health and Human Services, 2018), which is not in the context of visual aesthetic quality and inclusion.

Although active leisure areas are primarily evaluated by providing activities and elements that ensure functionality, the environment in which activity areas are planned, their accessibility, and their design are highlighted in individual urban guidelines. The public outdoor space must be designed not only functionally but also aesthetically attractive, both from the point of view of architectural quality and the interaction between the design quality of the public outdoor space and the natural environment. However, landscaping design can help define user groups, used materials and designs must be durable, robust, and adapted to the specific place, which is the responsibility of the client, developer, and designer (The Ministry of Local Government and Modernisation, 2019). The Prague public outdoor space design guidelines (Prague Institute of Planning and Development, 2020) highlight the importance of the nature of the surrounding environment in which active recreation areas are integrated. In the built environment, the active recreation areas should be more compact, using elements that provide activities of classic design. In contrast, in parks, open green spaces, and territories with minimal construction, a dominant natural environment should be integrated with more natural elements and materials, including the natural structures available in the surrounding environment.

## **Materials and Methods**

The study evaluates the visual aesthetic quality of the urban environment in the public outdoor space as one of the factors affecting the overall quality of the city, paying attention to the design solutions applied to active leisure areas, their aesthetics, and their interaction with the surrounding infrastructure.

The research examines examples of active leisure area design solutions for mutual interaction with the environment in which they are located. For more in-depth research, this study evaluates active leisure areas in Latvia, Riga, and similar areas in Estonia and Tallinn.

The active leisure areas selected in this study are based on principles included in the previous study (Janpavle & Īle, 2022) and include the proposed principles in the selecting territories and previously defined evaluation criteria, further continuing the study to evaluate the quality of public outdoor space in the context of active leisure areas. The study additionally determined the components attributable to the interaction of active leisure areas with the elements in the surrounding environment and existing urban design structures, evaluating the visual aesthetic of the design of the elements and their functionality.

The study evaluated the territories by dividing them into groups in courtyards, parks and squares, and promenades and choosing similar territories in Riga and Tallinn according to their distance from the city centre.

Based on the materials of scientific research literature, the method of mutual comparison was used to compare the surveyed areas. The obtained results were summarized in quality assessment tables and photographs.

## **Results and Discussion**

Worldwide and in Latvia, there are many positive examples of the planning of active leisure areas, which consider the surrounding environment's aesthetic qualities and the existing infrastructure's visual quality, complementing it with the selected elements while ensuring the necessary functionality. It can be connected with the requirements contained in the planning documents or the setting of the design guidelines for the development of specific areas, as well as with the experience and knowledge of the specialists in the relevant field, knowing the assortment of elements and materials available in the relevant region, their application and specifics.

For example, Berlin's urban planning documents (Berlin Senate Department for Urban Development Communication, 2011) emphasize an accessible environment for all, precisely describing specific requirements and aesthetic visual characteristics, which are more related to informative signs or specific designs that help to navigate the urban environment, mentioning, that the planning should not be oversaturated with too many contrasting elements, which can cause confusion and affect the ability to navigate for the users of the public outdoor space, at the same time indicating that the contrasts of light, colour, and form can help orientation in the environment. However, they must be appropriate to the specific environment's planning and the applied colour code, thus drawing attention to the fact that the visual aesthetic characteristics must be adapted to the specific environment in which the improvement is planned.

Tallinn's development strategy, 'Tallinn 2034' (Tallinn, 2020), mentions that public outdoor space should be pleasant, natural, and enriched with various activities that motivate people to spend time outdoors and be active. However, nothing is mentioned about how environmental improvements should look visually. Also, the urban design guidelines of Tallinn (Zaha Hadid Architects, 2017) do not specifically mention principles for visual aesthetic design concerning active recreation areas, but it is mentioned that the improvement should be attractive, inviting, and with high architectural, landscape architectural solutions and design quality, which complements the historic character of the city and is in context with the surrounding environment. Riga planning documents discuss integrating children playgrounds and recreational sports areas in green corridors, emphasizing the functionality of children playgrounds and recreational sports areas (City Development Department of Riga City Council, 2014, 2017).

In recent years, renovated and newly created active leisure areas have been positively evaluated in Riga, Latvia, where already at the level of city planning, it is thought about how such areas will fit into the urban environment, determining locally in the design task the conditions for structural elements, their functionality, colour and desired shape to match the surrounding environment, placing particular emphasis, but also ensuring the necessary activities and focusing primarily on the improvement of the areas closer to the city centre, making it more representative.

A positive example in Riga, Latvia, is the renovated children playground in Kanālmala greenery, located in the historical park in the central part of the city. The children playground has been modified several times over the years, keeping the sandbox space, which was already designed during the initial planning of the park to provide users with the opportunity to play with different materials, which resonates with modern trends to integrate a variety of materials, loose materials in the planning.

The children playground before the reconstruction in 2023 'Figure 1' included elements providing various functionality mainly for the youngest age group of users, and their visual aesthetic design in terms of shape and color of the structural elements contrasted with the existing infrastructure in the park, not in a uniform style 'Figure 2'. Over time, the elements included in the improvement had lost their aesthetic, visual, and functional quality. The safety cover was worn out and visually degraded, and even the concrete tiles around the trees were worn out. They did not fulfil their intended function, affecting the trees growing there and significantly lowering the overall visual quality of the area.



Figure 2. Photographic record of the elements and surfaces included in the children playground before the reconstruction in 2023 in Riga, Latvia.

After reconstruction at the end of 2023, the children playground 'Figure 3' changed its visual aesthetic overview, creating amenities that complement the surrounding environment, integrating elements with more comprehensive functionality for user groups of different ages, ensuring a harmonious integration into the park environment, highlighting the nature of the park greenery, ensuring neutrality in the materials used and in the elements, predicting the colour tonality of the elements matched to the tree trunks, avoiding bright colour accents, choosing the thematic elements applicable to the specific environment, creating transparent constructive elements, at the same time ensuring the functionality of the elements, safety and contrasts in the parts of the functional elements, where it is necessary. In the renovated children playground, the sandbox was supplemented with elements designed for sand play, integrating elements for moving sand, thus bringing new functionality that resonates with modern trends to include free-standing, movable components in landscaping.



Figure 1. Photographic record of the children playground before the reconstruction in 2023 in Riga, Latvia.



Figure 3. Photographic record of the children playground after the reconstruction in 2023 in Riga, Latvia.
This study evaluated eleven territories with active leisure areas, considering the nature of their planning and location at a distance from the city centre, surveying five territories in Riga, Latvia 'Figure 4' and six territories in Tallinn, Estonia 'Figure 5'.



Figure 4. The location of the territories surveyed in the study according to the distances from the city centre (1 – Sport quarter active recreation area in K. Barona Street; 2 – Business and a residential quarter 'Jaunā Teika'; 3 – Latgales park; 4 – Active leisure area near multi-story residential buildings on Lubānas Street; 5 – Ķengaraga promenade and Latgales, Krasta streets) in Riga, Latvia.

The optimal boundary of the accessible distance to the city centre is assumed to be 3.75 km, which defines the limit to which the public outdoor space is easily accessible within the framework of the fifteen-minute city concept, assuming that it is the maximum distance that can be travelled in 15 minutes by bicycle (Andersen, 2021).



Figure 5. The location of the territories surveyed in the study according to the distances from the city centre (1-Business and residential quarter 'Kalaranna kvartal', 2 -

Children playground next to the walking route 'Kulturikilomeeter'; 3 - Tondiraba park; 4 - Männi park; 5 - Active leisure area between multi-story residential buildings, Akadeemia street; 6 - Pirita promenade and Reidi Street) Tallinn, Estonia.

In Riga, Latvia, two studied areas fell within a radius of 3.75 km from the city centre. However, in the study, they are defined in a distance group that is further from the city centre than 3.75 km, which is related to the architectural and structural structure of the city, suitable transportation

routes for walking or with bicycle, and the total approximate distance to the city centre which in this case were longer comparing straight connections.

The studied territories are divided into three groups according to the type of use of public outdoor space - public outdoor space as a place (Business and residential quarter 'Jaunā Teika', Ropažu street 14 and active leisure area near multi-storey residential buildings at Lubānas street 14, Riga, Latvia; business and residential quarter 'Kalaranna kvartal', Kalaranna Street 6a and the active leisure area between multi-storey residential buildings, Akadeemia Street 30a, Tallinn, Estonia), public outdoor space as a destination (Active recreation area of the sports quarter of the centre, K. Barona Street 116a and Latgales Park, Latgales Street 154, Riga, In Latvia; children playground next to the walking route 'Kultuurikilomeeter', 10415 and Männi park, Sõpruse street 252, as well as Tondiraba park, 13917, Tallinn, Estonia) and public outdoor space as an intermediate point (Kengaraga promenade and Latgales Krasta streets, Riga, Latvia; Pirita promenade and Reidi Street, Tallinn, Estonia), active leisure areas in separate sections of the promenade, or the promenade itself as a connection and functional area for recreational sports activities, ensures the connection of the city centre with other neighbourhoods.

Areas surveyed in the study in Riga, Latvia 'Figure 6' and Tallinn, Estonia 'Figure 7' were evaluated according to the visual aesthetic characteristics of the infrastructure necessary for the provision of activities, evaluating the visual quality in general, determining whether it is maintained, partially maintained or not maintained. Evaluating whether it is visually compatible with the surrounding environment with visually expressive landscaping that complements the overall outdoor design, visually expressive landscaping that blends with the surrounding environment, visually expressive landscaping that does not fit with the surrounding environment, landscaping that complements the overall outdoor design, merges with the overall design of the outdoor space, or does not fit. Also, assess whether the applied materials and included elements are compatible, conditionally compatible, or incompatible with other components in the surrounding environment. In addition to determining whether the landscaping of the active leisure area includes elements, the overall design of the activity area or parts thereof is designed to provide added artistic value, which may be legible, conditional, or illegible.

The criteria for assessing the comprehensive visual quality of the territories identified in the study are divided into four groups. Points for the territory's compliance with the established criteria in evaluation systems are assigned from 0 to 2, and the average numerical evaluation of the total points of the territory is divided according to the rating distribution - low, medium, and high. Visual quality was evaluated with 0 points if the surveyed territory was not maintained, 1 point if the territory was partially maintained. Assessing whether the surveyed area is visually suitable for the surrounding environment, territories characterized by 0 points in the

study were not suitable or visually unexpressive, with 1 point territories that merged with the overall design of the outdoor space or complemented the overall design of the outdoor space, and 2 - visually expressive, blended in with the surrounding environment, or were visually expressive and complemented the overall outdoor design. When assessing whether the surveyed territories are compatible with other components in the surrounding environment, 0 points corresponded to the assessment that the territory is incompatible with other components in the surrounding environment, 1 - conditionally compatible, 2 - compatible. When evaluating whether solutions with added artistic value could be observed in the surveyed areas, 0 points indicated that the added artistic value was not legible, 1 point - conditional artistic value, and 2 - legible artistic value could be observed. A low rating in the study characterizes the surveyed territories with an average numerical result lower than or equal to 3 rating points out of 8 points, an average rating of 4 points, or a high rating of higher than 4 points.



Figure 6. Evaluation of the visual aesthetic quality of the territories surveyed in the study and mutual comparison of the territories (1 – Sport quarter active recreation area in K. Barona Street; 2 – Business and a residential quarter 'Jaunā Teika'; 3 – Latgales park; 4 – Active leisure area near multi-story residential buildings on Lubānas Street; 5 – Ķengaraga promenade and Latgales, Krasta streets) in Riga, Latvia.



Figure 7. Evaluation of the visual aesthetic quality of the territories surveyed in the study and mutual comparison of the territories (1- Business and residential quarter 'Kalaranna kvartal', 2 - Children playground next to the walking route 'Kulturikilomeeter'; 3 - Tondiraba park; 4 - Männi park; 5 - Active leisure area between multistory residential buildings, Akadeemia street; 6 - Pirita promenade and Reidi Street)Tallinn, Estonia.

Considerable examples of visually aesthetic improvement solutions of active leisure areas, which echo the components of the surrounding architecture and general area improvement, quality-defining characteristics, including matching the colour range contained in the surrounding environment and the structural characteristics of elements or other architectural and natural components, are the surveyed area in business and residential in the quarter 'Jaunā Teika', Ropažu street 14, Riga, Latvia 'Figure 8', business and residential quarter 'Kalaranna kvartal', Kalaranna street 6a, Tallinn, Estonia 'Figure 9'.



Figure 8. Photographic record of the children playground in the 'Jaunā Teika' residential block, Ropažu Street 14, Riga, Latvia.



Figure 9. Photographic record of the active leisure area in the business and residential quarter 'Kalaranna kvartal', Kalaranna Street 6a, Tallinn, Estonia.

Both of these areas are relatively recently built, and the landscaping is planned to be interrelated with the overall public outdoor space, including active leisure areas, planning of sidewalks and squares, greenery, quiet recreation areas, and other parts of public outdoor landscaping.

In areas where the improvement of active recreation areas has been formed at different times compared to the surrounding infrastructure, the surrounding environment is outdated or partially degraded and

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located further from the city centre, the improvement of active leisure areas is less expressive, without added artistic value, with the main emphasis on ensuring functionality. For example, we can take the surveyed active leisure area near multi-story residential buildings at Lubanas Street 14, Riga, Latvia, 'Figure 10', where a children playground and a recreational sports area have been created, using typical solutions without expressive colour or shape accents. The surrounding environment has outdated landscaping, and the active leisure area is relatively isolated from the rest of the infrastructure; therefore, it does not significantly affect the overall visual quality of the environment but rather improves it by integrating additional functionality into the overall landscaping, as well as the elements providing functionality are neutral in shape and colour, qualitatively, without significant signs of wear and tear, creates the impression of an orderly environment.



Figure 10. Photographic record of the active leisure area near multi-story residential buildings at Lubanas street 14, Riga, Latvia.

The active leisure area of the Sports guarter of the centre, K. Barona Street 116a, Riga, Latvia, examined in the study, is designed with multifaceted activities, concentrating in one place, in a large area, among the historical buildings of the centre. These various structural and visually different elements conditionally resonate with the surrounding environment, rather partially torn from the surrounding environmental context. The positive aspects in this area are the efforts to bring in artistically refreshing elements, to highlight the identity of the place, and to integrate the events and landmarks characteristic of Riga into the design of the elements, for example, the church towers 'Figure 11', the participants of the Song and Dance Festival. There needs to be more greenery that would help integrate landscaping into the surrounding environment.

In the surveyed Männi Park, Sõpruse Street 252, Tallinn, Estonia, there were also observable elements with an added artistic value, 'Figure 12', creating functional components in the theme of birds and insects. Taking into account that the landscaping with various activity areas was integrated into the existing park as part of the overall park reconstruction, in general, the integration of the active leisure area into the surrounding environment can be evaluated as visually appropriate and with expressive landscaping that matches the mood of the surrounding environment and the included theme complements the surrounding environment.



Figure 11. Photographic record of the active leisure area of the Center Sports Quarter, K. Barona Street 116a, Riga, Latvia.

The main aspects of shifting the aesthetics of elements in the background towards functionality can be related to the insufficient coverage of active leisure areas in the urban environment and limited funding that can be allocated for the establishment of such areas, as well as the location in the city plays a significant role in the visual quality and design complexity of the elements in areas further from the main primary providing functionality without taking into account the visual specifics of the surrounding environment.



Figure 12. Photographic record of Männi Park, Sõpruse Street 252, Tallinn, Estonia.

Visual changes of elements or adaptation to specific visual requirements of the surrounding environment can significantly increase the cost of the element. Such an increase in the cost of increasing the visual quality is related to the specifics of production and the ability to adapt to the necessary changes outside of the production process of standard elements. However, this does not mean that specialists who plan this type of activity area cannot find elements suitable for the specific environment within the limited funding that would not conflict with the existing landscaping. Therefore, the visual quality of the active leisure areas can be linked to the professional abilities of planners and customers in choosing elements or the visual aesthetic properties of their components.

#### Conclusions

- 1. The influence of active leisure areas on the visual quality of the urban environment is an essential aspect that must be taken into account when planning new active leisure areas or renovating existing ones, choosing elements that ensure the necessary functionality and visual aesthetic quality not only within the activity area, with mutually consistent elements, but also in the context of the surrounding environment, ensuring the overall integration of the design solutions of the active leisure area into the overall visual aesthetic image of the surrounding environment.
- 2. The quality of the surrounding environment significantly impacts the creation of active leisure areas, primarily by providing the missing and necessary functionality in the surrounding area and adjusting the design of elements to be aesthetically consistent with the surrounding environment. In places where the surrounding environment is assessed as insufficient or low, the integration of active leisure areas can improve the overall visual quality of the area, positively influencing the overall quality of life.
- 3. Evaluating the territories in Riga and Tallinn examined in this study, the conclusion is that several active leisure areas can be considered as examples of good practice, where the choice of

elements and the overall infrastructure of the active leisure area is designed taking into account the aesthetic features of the surrounding environment by highlighting or supplementing them, which can be linked to the fact that, in general, the territory has developed later and its character is more adapted to modern functional and aesthetical urban design solutions. In areas where the environment is outdated or has lost its aesthetic visual quality or is located further from the city centre, the main emphasis is placed on the functionality of the elements, primarily providing play and sports activities, implementing solutions that are more neutral from the design perspective, lowering complexity or visual quality, or implementing standardized solutions for the planning of activity zones, which could be observed in several surveyed areas in Riga.

4. When evaluating the visual aesthetic aspects of the already implemented active leisure areas, it should be considered that the general image of each territory is significantly influenced by the overall visual and physical nature of the particular territory, specific requirements concerning adjustable standards, or significant restrictions, subjective aspects of the customer and the designer, which are related to the available funding or necessary functionality, planning experience and understanding of visual aesthetic inclusion in the context of the relevant environment as well as user experience, generalizing specific needs and community vision.

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# URBAN AND PERI-URBAN FOREST AREA STAKEHOLDER IDENTIFICATION, CASE STUDY OF 'BERNĀTI' AND 'OGRES ZILIE KALNI' NATURE PARKS

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# Abstract

Stakeholders and involved parties are crucial in a proper management of forest areas, more so in nature park areas. Urban nature areas and more remote peri-urban areas have objectively the most complex management issues due to the potentially high density of visitors and a diverse range of stakeholders. Such areas can also be valuable nature conservation and biodiversity hotspots, further making stakeholder interactions more complex. In this research, we conduct stakeholder identification for two case study areas – an urban forest nature park and a peri-urban forest nature park, with the aim of developing detailed lists of involved parties, including both public and private entities. We identified three main blocks of stakeholders (regulatory, usage, management), and detailed each group and sub-group for the case study areas. Our main results and conclusions include the identification of minor differences particularly explained by geographical and socio-economic contexts for each of the areas, with the regulatory stakeholder group overlapping the most between the two areas. The potential use of such analysis can improve or develop cooperation between previously unobserved stakeholders, and in research area.

Key words: stakeholders, urban forest, peri-urban forest, nature park.

# Introduction

In the management of urban and peri-urban forests, in addition to the specific principles of forestry, good governance is also necessary. This applies both to the organization of state, sector or company processes, which are based on their management principles, methods and techniques, and to the principle of good governance as a principle of administrative law (Kovalevska, 2009). According to Kovalevska and other authors, good governance in any sector or company activity requires transparency, responsibility, accountability, involvement of people affected by decision-making, responsiveness to the needs of the population, efficiency, resource saving, accommodating, constructive and interested attitude, which is directed towards problem solving, equal information for everyone about opportunities, clearly understandable rules and decision-making process, personal disinterest, justification of decisions and substantive responses (Jones, 2007; Kovaļevska, 2009). A form of public participation which can also be applied in urban forest planning and management includes the right to submit a request, public investigation, local referendums and consultation committees. residents' discussion clubs. communication and discussions on the internet, children's councils, minority representation, open seminars, proactive expression of residents' ideas and desires (Jones, 2007). It is also necessary to use the

internal cooperation resources of the forestry sector, cooperation at the local, municipal and regional levels (Kenney, van Wassenaer, & Satel, 2011). Forest management nowadays is based on the

principles of sustainability and focuses not only on timber yields but also strives to integrate and ensure the environmental and social functions of forests. Urban and peri-urban forestry differs significantly, because timber production takes a secondary role or is not employed at all due to nature protection requirements, with the social function being highlighted as the most important. In Latvia, all forestry work planning and operations take place in accordance with the Forest Law, which requires the development of a forest management plan (FMP) for the actual forestry activities. This is a second-level plan based on forest inventory data, which sets out the basic principles and volumes of forest management and use, and updates the nature conservation and protection action plan for the next ten years until a new forest inventory. Initially, the municipality had no influence on forestry planning. Significant changes were brought about by amendments to the Forest Law - Article 2, Paragraph 5, which stipulates that forest management must not contradict the requirements of territorial development planning documents (Latvijas Republikas Saeima, 2000). Foresters had to reconcile with the rules that introduce a new stakeholder in forest management - the municipality. The greatest dissatisfaction of foresters was with each municipality's 'individual forest policy', which provides for rules different from the Forest Law. Until 2012, the role of foresters in the development of municipal territorial planning was mostly more or less passive, limited to the role of information provider (for example, general data on the forest in the municipality, on logging volume and the like can be found in development plans.

The most interested party in the management of forests and urban forests in Latvia is the state, which forms the general normative base, supervision, and assistance. The Saeima issues laws regulating the forestry sector (Latvijas Republikas Satversmes sapulce, 1922). The Cabinet of Ministers issues binding Cabinet regulations, which more precisely regulate specific activities (Latvijas Republikas Saeima, 2008). The State Forest Service (SFS) within its competence supervises forest management and use and compliance with regulatory acts regulating hunting, supervises and implements forest fire fighting, and participates in the development and implementation of state forest policy (Latvijas Republikas Saeima, 2000). The State Environmental Service's goal is to ensure compliance with regulatory acts in the field of environmental protection, radiation safety and nuclear safety, and natural resource use, as well as to promote sustainable use of natural resources and energy. One of the functions is to carry out state control of environmental protection and natural resource use in Latvia in the manner prescribed by regulatory acts governing environmental protection (Latvijas Republikas Saeima, 2004). One of the functions of the Nature Protection Board is the management of specially protected nature territories (hereinafter - protected territory) established by the Saeima and the Cabinet of Ministers (Latvijas Republikas Saeima, 2009), many of these territories are also forest territories. The State Police is a direct administration institution under the supervision of the Minister of the Interior, which, within its competence, implements state policy in combating crime and protecting public order and safety, as well as protecting the rights and legitimate interests of individuals (Latvijas Republikas Saeima, 2005), in the Law 'On Police' and other regulatory acts regulating the activities of the State Police (Latvijas Republikas Saeima, 1991). State Fire and Rescue Service. Forest fire fighting is a set of measures that in the forest and forest lands ensures the detection of the forest fire site, containment and extinguishment of the fire, and monitoring of the fire site (Latvijas Republikas Saeima, 2003).

One of the autonomous functions of the municipality is to promote the sustainable management and use of natural capital, as well as to determine the use of municipal property in public use, if not otherwise provided by laws (Latvijas Republikas Saeima, 2022). The Building Authority, in fulfilling one of the autonomous functions of the municipality, ensures the legality of the administrative process related to the construction process (Latvijas Republikas Saeima, 2022), among other things, also in all forest territories. Municipal police. The autonomous function of the municipality is to participate in ensuring public order and safety, including establishing and financing the municipal police (Latvijas Republikas Saeima, 2022). The municipality establishes a municipal police, the duties of which include the prevention of violations, control over the fulfillment of binding regulations of the municipality (Latvijas Republikas Saeima, 1991). In essence, municipalities are tied to forest management in their territory, but in practice, they usually have little influence on the forestry process, including urban forests. Forestry indirectly affects the economic life of the municipality's territory, promotes employment, and maintains or creates traditions. If income from forestry directly affected municipal income, it would more carefully consider a strict stance on the economic use of forests. All forestry work planning and implementation takes place in accordance with the Forest Law, in which the municipality is assigned a negligible role. As mentioned before, Paragraph 4 of Article 2 of the Forest Law provides that additional conditions for forest management in urban and rural areas are also provided by binding regulations of the municipality (Latvijas Republikas Saeima, 2000). Significant for spatial development planning is Paragraph 5 of Article 2, which provides that forest management must not contradict the requirements of territorial development planning documents, (in force from 01.01.2012) (Latvijas Republikas Saeima, 2011), which also imposes an obligation on foresters to consider the interests of municipalities in forest management. A certain problem is caused by the fact that municipalities do not have a convincing opinion on forest territory planning, functional zoning, and appropriate management yet. So far, in most of the Riga agglomerate municipality territory plans, the forest is marked as a continuous green mass, without distinguishing different forest functions; therefore, it is not shown which of the forest functions has a leading role in a particular territory, what level of improvement is needed. Forest improvement, creating parks, forest parks falls on the shoulders of municipalities, but unfortunately, for this purpose, municipalities can afford to allocate limited resources, at best performing negligible improvement work.

An association is a voluntary association of persons established to achieve the goal set out in the statutes, which is not of a profit-making nature (Latvijas Republikas Saeima, 2003). Urban forests are resources that a certain group of people manage to raise the wellbeing of other involved groups, so the mutual communication of these groups is important to achieve the set goals. In city forests, not only forest specialists, but also representatives of other sectors - landscape architects, city planners, spatial development planners, environmental specialists. health institution representatives, and other professionals are gaining more and more influence. The urban forest manager has to work in interaction with other involved professionals and society. Latvia lacks, transparent public discussion and decision-making procedure for the balanced use of the ecological, economic, and socio-cultural value of the forest, the economic viability of forest management is threatened. As a result of poor mutual communication, unnecessary conflicts can arise between all involved participants (forest owners, foresters, municipalities, state administration, society, press), followed by incorrect use of available work resources (for example, emergency actions to resolve conflicts) and a fragmented management system. Such a situation also limits public participation, as it is not clear to the public who is responsible for what and who to turn to in each specific case. All this can affect sustainable urban forest planning and management. Participation is rarely a simple process. In foreign countries, various groups and participants are involved in urban forest management (Konijnendijk *et al.*, 2005), which should also be achieved in Latvia.

Participation of society in decision-making processes in any municipality is an integral part to ensure effective governance. The participation of interest groups at the initial stage of the planning process allows for the development of various compromise options that satisfy the target groups. However, in reality, public involvement still occurs in very small volumes, or in cases of sharp conflicts. The reasons for this can be attributed to societal inertia, low levels of trust in the existing power, formal interest of municipalities in public participation, and the historical secrecy of forestry planning.

Considering all these issues, our research goal includes the identification of stakeholders and setting a baseline for further identification of conflicts or synergies. This is important to not miss a crucial involved party and to draw a holistic picture of the state of management of an area.

#### **Materials and Methods**

In this case study, we utilized various base sources and described the state of the stakeholder relationships in the context of our two case study areas. We analyzed the study areas through the following resources - national laws (including Forest Law and others), regulations and municipality level regulations. The 'map' of stakeholders was created by going through the corresponding levels from top to bottom (starting with the national body of regulations, ending with the public use of the area. We consolidated the main stakeholder groups and activities in a single table for both case study areas and checked for subsequent differences in the types of stakeholders or nuanced uses of the forest area. Inferred experiences and observations through the viewing glass of researchers and forest area managers were also employed, but the main body of this case study consists of using formal documents, with the inferred views only adding details to the overall context. For our research, we selected two relatively distinct, yet similar forest areas – Ogres Zilie kalni nature park (located in the vicinity and immediate agglomeration of Riga), the area we classify as urban, and Bernāti nature park, located approximately 220 km from Riga, at the coast of the Baltic Sea, see 'Figure 1'.



Figure 1. Location of the case study areas.

We classify Bernāti as a peri-urban forest area, since the immediate vicinity of the nature park contains a small village and agglomeration of rural houses, and a major city approximately 15 km away. The two areas share features of the status of a protected nature park but consist of different management and ownership zoning. While the Ogre case study area is a major hotspot for recreational activity and visited by tens of thousands of visitors in the context of Riga agglomerate (capital city of Latvia), Bernāti is less popular on the national scale, thus, inferring population distribution in Latvia and has fewer total visitors. Bernāti nature park is more focused (through zoning and regulation comparisons) on nature conservation and species diversity issues, which are increasingly problematic in the context of an influx of recreational visitors in the past 10 or so years. Foreign tourists and locals increasingly utilize the area for recreational activities, and the land owners and managers are adapting by introducing various infrastructure projects and steering visitors from sensitive nature protection zones.

#### **Results and Discussion**

Our main result is the analysis of stakeholder distribution for the two case study areas (the stakeholders we have identified) (Table 1). We divided the identified stakeholders according to the main stakeholder groups, and subdivided by specific case study stakeholders (the ones identified in our research). Thus, we can compare which stakeholders are transient and overlap despite geography or type of area, and which are unique.

Table 1

Stakeholder group	Stakeholder	Function and involvement	Ogre Zilie Kalni nature park (urban)	Bernāti nature park (peri- urban)
National Government	Saeima (Parliament)	Lawmaking and regulations	State and municipal divisions (regional offices) of various regulatory, enforcement or oversight services are functionally the same and with unifie standards on the national scale.	
	Cabinet of Ministers	Regulatory rules		
	VMD (Forest Service)	Enforces laws and rules based on forestry management		

Identified stakeholders and comparisons between the two case study areas

			0	Continuation of the Table 1
	VVD	Environmental protection		
	(Environmental	and regulations concerning		
	Agency)	Noture protection aspects		
	DAP (Nature Protection	enforcement territory		
	Agency)	management		
	VUGD (Fire and	Fire safety, rescue and		
	Rescue Service)	criminal investigations and		
	and Police	prevention		
	Municipality council	Local laws and regulations	Ogre municipality	Dienvidkurzemes municipality
Local Government	Construction, planning and inspection services	Oversight and allowances of buildings, proper use of territory type	Ogre municipality	Dienvidkurzemes municipality
	Municipal Police	Enforcement of public safety, decency	Ogre municipality	Dienvidkurzemes municipality
	State owners	Management of state owned land	No state owned land	Latvian State Forests and Government of Latvia
	Municipality owners	Management of municipality owned land	Ogre municipality and Riga city	Dienvidkurzeme municipality and Liepaja city
Landowners	Public owners	Management of public entity land	Municipality owned 'Ikšķiles māja'	Undefined public or state ownership of smaller land parcels
	Individual owners	Management of privately owned land	None	Groups of small (~10ha each) historically privately owned forest parcels
	Individuals, local citizens	Recreational use, sports, hunting, photography, foraging and others	Both areas are inclusive and open to recreational activities outside restricted nature protection zones Camping (tents, fireplaces) is regulated by law	
Community, society	National scale citizens	Tourism, as above		
	Foreigners	Tourism, as above		
Educational institutions	All-levels of educational system, interest based education	Environmental education, sports, internships	Various educational institutions in the Ogre municipality and from Riga actively use the area	No known organized activities by educational institutions on a regular basis, closest educational facilities are around 6 km away
Armed Forces	National Guard, Youth Guard	Field training, competitions, other events	Various National Guard or Armed Forces units	No activities published or announced
	Tourism and guided tour related	Guided tours, tour services, nature education services	Proximity to Riga defines broader services and organizations offering services	Lesser active promotions of guided services
For-profit business	Services	Craft services, bed and breakfast, event spaces, services related to forest management	Not directly in area, but proximity to Ogre city and Riga provide large amount of services	Locally owned caffes (2), large number of lodgings (private and public) due to proximity to the sea coast
NGO's	Nature protection and civic activity related	Involved in oversights on strict nature reserve territories, species and biodiversity issues	'Nature protection club', other state wide environmental NGO's	Residents organization 'Mēs Bernātiem' (local community NGO), other state wide environmental NGO's
	Educational	Nature education events, programmes, campaigns	State wide events and o distinctiv	campaigns for both areas, no re events found

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		C	Continuation of the Table 1
Sports, fitness, survival schools	Miscelleanous events, programmes, campaigns and events	Biathlon club, skiing club, orienteering club, bikeriding federation, other sports clubs	Orienteering club, mountain biking club. Events by other state wide organizations rare

Considering the stakeholder relationships and structures in the context of an urban or peri-urban forest area, we identified three main groups or clusters – regulatory, management and usage stakeholders. As seen in the schematic, see 'Figure 2', the relationships all 'meet' at the center, the forest area itself, and this can also be interpreted as a pressure point, as all of the stakeholders contend or enforce their interests or necessities.



Figure 2. Schematic representation of the stakeholder involvement and role distribution for a general forest area.

As expected, there were miniscule differences in the regulatory aspect of stakeholders - both areas are essentially under the state law as nature parks and contain nature protection reserve. Regulatory stakeholders differ only by their regional location, but are all with the same rules, enforcements, laws. Main differences arise in the land ownership and management aspects - Bernāti nature park is more fragmented, due to either historical or chance factors. In comparison to the Ogre case study area, a more undefined cooperation must exist between the two municipalities, the state owned forest areas and a reasonable amount of small private land holders. We were unable to delve deeper into these relationships in the Bernati case, but in comparison to Ogre Zilie kalni, where the ownership is more homogenous, it is debatable whether this increases or decreases certain development projects or management issues.

In terms of public usage (multitude use by the wider community of both visitors and locals), the characteristics of both forest areas show similarities, yet certain aspects are missing in either case – there are no skiing or other winter sports clubs in Bernati, compared to Ogre, even though the nature park does contain elevation aspects. This could be explained by stricter zoning concerning nature protection areas. In Ogre, no public/local resident's NGO was identified - this differs from Bernāti, where a reasonably active NGO is present and even organizes the development and community events in the nature park. Few differences arise from certain other aspects, like the use of areas by armed forces. In the Bernāti case, we could not identify any known use by the National Guard, as was in the case for Ogre Zilie kalni. This could be explained once again by the more nature protection centric regime of the Bernāti area. Bernāti also showcases a difference in the use of tourism attractions in the vicinity and the immediate location (including one such site inside the nature park, which is a municipality owned camping/resort site) is filled with guest houses, RV and tenting sites. This differs from Ogre, where the close vicinity to the urban area might have an adverse effect on the willingness to spend a night or develop such housing. As both areas differ by the classification we employed (one is peri-urban, other is urban), these differences also show in a more nuanced analysis of stakeholders. The aspects of forestry management in terms of logging, was unexplored thoroughly, but was not a critical element of this analysis due to the fact that the areas are nature protection areas a priori.

# Conclusions

- 1. In both research areas, all relevant stakeholder domains are visible, including regulatory activities and property rights - management and utilization. Uncertainties rise from the public and private use of the areas, as all recreational or other types of uses are difficult to identify.
- 2. No informal resident's association has formed in the Ogre Zilie kalni to address territorial development issues. It can be concluded that the comprehensive development functions of the territory are carried out by the municipal agency, which manages the area and actively communicates with residents/visitors by listening to their opinions and explaining actions.
- 3. Continuing research on the interests of the Ogre Zilie kalni and Bernāti to supplement the specific engagement of interested parties is necessary. Further study of other urban areas would confirm our claims regarding interested parties or expand their enumeration.

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# DISSOLUTION BEHAVIOUR OF BLACK ALDER BARK EXTRACTIVES IN POLYURETHANE SYNTHESIS MEDIA: A COMPREHENSIVE STUDY

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# Abstract

Two approaches to incorporating black alder (BA) bark extractives-derived polyol into a polyurethane (PU) network were studied. In the first case, fractionation of bark extractives with tetrahydrofuran (THF), focusing on isolating the biomass fraction available for obtaining PU elastomers by casting methods using cyclic ethers as a solvent, was employed. Another approach aimed to obtain liquid bio-polyols that could be suitable for producing rigid PU foams. For this purpose, oven-dried crude BA bark water extracts were liquefied with polyethylene glycol (PEG 400) at temperatures of 130-170°C. The effect of adding sulfuric acid as a catalyst on biomass processing was studied. Wet chemistry, GC, FTIR spectroscopy, analytical pyrolysis (Py-GC/MS/FID) and rheological methods were employed to characterize the obtained polyols and insoluble fractions, enabling an assessment of biomass transformation during processing. The resulting THF-soluble fraction comprised 62% of the BA bark extract, mainly consisting of the xyloside form of the diarylheptanoid compound oregonin, along with oligomeric flavonoids and carbohydrates. The THF-insoluble fractions were predominantly composed of carbohydrate compounds. Moreover, it was observed that the PEG 400-insoluble fractions were predominantly composed of carbohydrate components. The results indicated that the use of sulfuric acid as a catalyst (1-1.5% of solvent) promotes the complete liquefaction of extractives, enabling biomass content in polyols of up to15-25%. Surpassing the extract content in the starting suspension up to 30% resulted in incomplete liquefaction of biomass. These findings offer valuable insights into tailoring BA bark extractives as building blocks suitable for obtaining PU materials.

**Keywords:** bark, extraction, fractionation, liquefaction, polyurethane, plant polyphenolic.

#### Introduction

In modern human society, plastics are indispensable materials with a global annual production of about 391 MT in 2021, expected to triple by 2060 (European Commission, n.d.) More than 97% of plastics are derived from fossil resources, not available for biodegradation, and therefore make a significant impact on the emergence of environmental and economic problems (Chem4Us, n.d.). Alternative feedstocks must be biobased and therefore renewable monomers, thus reducing the industry's dependency on fossil-based materials and possessing the circular life cycle of plastic materials. This task is highly urgent in the PU materials industry, which comprises the most versatile class of polymers with a continuously increasing global market (Ma *et al.*, 2022).

Today substituting fossil-based polyols with renewable alternatives in isocyanate-based PU is recognized as the most viable pathway for the development of bio-based PU plastics (Rubens et al., 2022). The lignocellulosic biomass composed in major from plant polyphenolics and carbohydrates which are reached in phenolic and aliphatic OH respectively are recognized as one of the readily available natural resources for biobased polyol obtaining (Phung Hai et al., 2021). Lignin and tree bark biomass the multitonnage underexploited wastes of pulping and timber industry correspondingly were lignocellulosic components most studied as a precursor of bio-polyol available for PU obtaining (Dizhbite et al., 2012; D'Souza et al., 2014; Mahmood et al., 2016). The transition of lignocellulosic materials from a solid to a liquid state via their chemical modification or dissolution in inert (aprotic) solvents or polyols used in PU synthesis serves as the basis for developing approaches to their use as macromonomers in PU

systems (Belgacem & Gandini, 2008).

The widely used chemical modification through oxypropylation transforms solid biomass into liquid polyols with uniform OH functionality and allows obtaining rigid PU foam with properties comparable to those of commercial materials (Li & Ragauskas, 2012; D'Souza *et al.*, 2014). But, the high temperature (200-250°C) and pressure (20-30 bar) increase the risk of fire and explosion, and low scalability does not allow characterizing this processing as sustainable.

In this work, alternative and more sustainable methods of lignocellulosic biomass liquefaction without deep chemical modification were applied. These include the fractionation of biomass by dissolving it in THF as an aprotic solvent utilized for obtaining PU elastomers through the casting method (Arshanitsa et al., 2016; Arshanitsa et al. 2023a; Arshanitsa et al., 2023b), and the liquefaction of biomass using a hydroxyl-rich solvent such as PEG 400, with a focus on the possible application of liquid products for rigid PU foam production (Gosz et al., 2020). The ease of feedstock approach, low labor, and short time required for the isolation of extractives using a green solvent, high yield of extractives (~20% on DM of bark), the presence of phenolic and aliphatic OH groups capable of condensation with isocyanate, and the oligomeric form of constituents motivated the choice of BA bark extractives as an object of investigation. The properties of bark extractives-derived polyols and the chemical alterations in crude extractives after the isolation of a fraction suitable for obtaining PU were studied and discussed.

# Materials and Methods

Bark removed by handle debarking of black alder (*Alnus glutinosa*) harvested in Talsu municipality of Latvia was used as a biomass feedstock. The extraction

of bark was performed by water at  $90^{\circ}$ C using microwave extractor of original construction followed by filtration and lyophilization as described (Arshanitsa *et al.*, 2022; Pals *et al.*, 2022). The THF was applied for fractionation of BA extractives at solid/liquid ratio 1:10 (w/v). The undissolved fraction was separated by filtration. The soluble fraction after distillation of THF was redissolved in water and lyophilized again.

OH, functionality crude and THF fractionated BA bark extractives was analyzed in duplicate by <sup>31</sup>P NMR using 600 MHz Bruker (Biospin Rheinstetten, Germany, BASIC PROBHD) spectrometer as described in (Arshanitsa *et al.*, 2023a).

The total phenolic (TPC) content in crude and fractionated BA bark extractives expressed as grams (g) of gallic equivalent (GAE) per gram of dry biomass was determined by wet chemistry methods (Singleton *et al.*, 1999).

The BA bark water extract was mixed with polyethylene glycol with Mn=400 g·mol<sup>-1</sup> under different conditions. These conditions included a temperature range of 130-170°C, a catalyst concentration ranging from 0% to 3% of H<sub>2</sub>SO<sub>4</sub> by weight of PEG 400, and a bark extract content ranging from 15 to 30% in the PEG 400-extract mixture. Consequently, the bark water extracts were fractionated into PEG 400-soluble polyol and PEG 400-insoluble fraction. The acid used as a catalyst was neutralized after solubility experiments through the reaction represented by equation (1), and the resulting water generated during the reaction was eliminated from the obtained biopolyol through continuous heating of the liquefied mixture at the designated temperature while blowing nitrogen through it.  $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$ (1)

The sum of monomeric sugar content including C6 (glucose, galactose, rhamnose) and C5 (xylose, arabinose) was determined by GC method after complete hydrolysis of biomass (Pals *et al.*, 2020).

Radical scavenging activity of crude and THF fractionated extracts was evaluated using the stable 2 2-diphenyl-1-picrylhydrazyl free radicals (DPPH') test (Dizhbite *et al.*, 2004; Lauberts *et al.*, 2017).

The Py-GC/MS/FID analysis of crude BA extract, its PEG 400 insoluble fractions was performed at 500°C (heating rate  $600^{\circ}$ C·s<sup>-1</sup>) using a Frontier lab Micro Double Pyrolizer Py-3030D directly coupled with Shimadzu GC/MS/FID-QP device (Arshanitsa *et al.*, 2021).

The Spectrum One spectrometer (Perkin Elmer) was used for study of FTIR spectra of biomass. The KBr technic was employed for preparing of samples. Each spectrum was scanned in duplicate.

The OHV of polyols containing liquified biomass were determined by acetylation method (Zakis, 1994) Viscosity of polyols was determined at 25°C using Modular Compact Rheometer. Each test was performed in triplicate, followed by the calculation of the average value and standard deviation (Std). Water content in polyols was determined by Karl Fischer titration.

# **Results and Discussion**

The yield of extractives isolated from BA was  $18.4\pm2.0$  % on DM of biomass. The yield of BA bark extractives fraction soluble in THF and therefore available to condensation with isocyanate as biopolyol for obtaining of PU elastomers by casting method consisted of  $62\pm2\%$  on DM of extractives. The relative content of phenolic and carbohydrate

constituents in raw extracts differs strongly from that of THF soluble and insoluble portions (Table 1).

Table 1

The total polyphenolic (TPC) and monomeric sugar content (average ± Std of three parallel tests) in crude and THF fractionated BA bark extractives

Index	Crude extract	THF-soluble fraction	THF-insoluble fraction
TPC, GAE, $g \cdot g^{-1}$	0.50±0.20	0.72±0.35	0.15±0.10
Sugar content, %	40.5±2.6	32.3±1.9	51.8±2.7

It was shown that due the moderate polarity ( $\epsilon_{20^{\circ}C} = 7.43$ ) THF promote the dissolution of plant polyphenolic versus that of more polar free carbohydrate. The content of polyphenolic in biomass was decreased in the raw: THF-soluble fraction  $\geq$  crude extract  $\geq$  THF-insoluble fraction. At that time the insoluble fraction is the most enriched with carbohydrates followed by crude extract and THF-soluble fraction (Table 1).

The presence of carbohydrates in THF-soluble fraction determined allowed proposition that they transfer to the THF-soluble fraction predominantly as phenyl glucosides. It was confirmed by HPLC data presented in our earlier manuscript (Arshanitsa *et al.*, 2023b). It

was shown that oregonin - xylodised form of diarylheptanoid is the dominant component of THF soluble fraction. NMR <sup>31</sup>P approved the mentioned results indicating the highest content of hydroxyl groups which by 90% presented by aliphatic ones in THF insoluble fraction. OH, functionality in THF-soluble fraction consists of almost equal proportion of alcohol and phenolic groups 'Figure 1a'.

Furthermore, the radical scavenging activity of the extract fractions, which is dependent on the phenolic compounds content, was evaluated using the stable 2 2-diphenyl-1-picrylhydrazyl free radicals (DPPH') test and expressed as the  $IC_{50}$  value (the concentration required to inhibit 50% of the initial free radicals).



Figure 1. The content of OH groups total and differing by origination in crude and THF fractionated BA bark extracts according to <sup>31</sup>P NMR (a); the biomass concentration required to inhibit 50% of DPPH<sup>•</sup> radicals (b).

A lower IC<sub>50</sub> value indicates higher radical scavenging activity. The THF-soluble fraction exhibited the highest activity, surpassing both the crude BA bark extract and the synthetic antioxidant Irganox 1010 widely used in PU materials (Xiao *et al.*, 1994). Conversely, due to the increased content of free carbohydrates and decreased content of phenolic compounds, the THF-insoluble fraction displayed significantly reduced radical scavenging activity compared to the crude extract, see 'Figure 1b'.

This fact allows us to consider the THF-soluble fraction of BA bark extractives as bio-polyols which could act in PU matrix simultaneously as macromonomers due to condensation of aliphatic and partly phenolic OH with isocyanate and as radical-scavenger due to the presence of remaining free phenolic groups. As a result, the substitution of PEG 400 up to 100% by THF–soluble fraction allows for a significant increase in the heat resistance, thermal stability in air, and mechanical properties at tensile of PU elastomers obtained by casting methods (Arshanitsa *et al.*, 2023b).

Another approach was used to liquefy the BA bark extractives in PEG 400 with a focus on the application of liquid polyols for producing rigid PU foam. The crude BA bark extract was mixed with PEG 400 under different conditions. The effects of biomass in the starting suspension, conversion temperature, the addition of sulfuric acid as a catalyst, on the

liquefaction yield, viscosity, and hydroxyl value of polvols obtained were investigated. The vield of liquefaction was defined as the amount of biomass soluble in PEG 400 at given conditions and expressed as a percentage of the starting biomass weight in suspension. A yield of 100% means that the insoluble fraction was not detected in the final product using the analytical procedure described above, and therefore complete conversion/liquefaction of biomass was recognized in this case. During a 6-hour-long dissolution process, it proved challenging to fully dissolve the BA bark extract (at weight ratio of 20%) in PEG 400 to achieve complete liquefaction without the use of a H<sub>2</sub>SO4 as catalyst, see 'Figure 2a'. In this case the trend of increasing liquefaction yield was observed with increasing of processing temperature. But anyway about 15% of starting biomass was not converted in liquid polyol at 150-170°C. With the addition of 0.5% catalysts, the complete dissolution of the introduced extract in PEG400 was not achieved, resulting in an insoluble residue of approximately 16-20%. However, when the catalyst concentration was increased to 1%, a notable improvement in solubility was observed at these PEG 400-extract ratio. At a temperature of 130 °C, the insoluble portion decreased to only around 9%, while at 150°C and 170 °C, all of the introduced bark extract dissolved, enabling the attainment of a 20% concentration of biomass in liquid polyol, see 'Figure 2a'.





b

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Further examination of BA bark extractives liquefaction in PEG 400 at variable biomass content in starting PEG 400 suspension in the range of 15-30% and fixed 1% of catalyst content indicated that for suspensions with 15% biomass content, complete conversion of extract at all tested temperatures was achieved, see 'Figure 2b'. However, at higher extract content of 20%, complete liquefaction was not achieved at 130°C but only at 150°C, and only at 170°C when the starting concentration of biomass was 25%. When the extract content was increased to 30%, complete dissolution was not possible at any of the temperatures utilized, leaving about 6-7% of solid in the final products, see 'Figure 2b'. Isolation of insoluble parts from the products of extractives liquefaction could allow the obtainment of liquid polyols containing about 25% of liquefied biomass, which is similar to that obtained by complete liquefaction of 25% biomass suspension performed at 170°C. This allows proposing that a 25% content of BA bark extractives in the starting suspension is the maximal for BA bark extractives complete liquefaction by PEG 400 under the conditions under study. Obviously, the further increasing of starting BA bark extractives content in suspension results in the decreasing of solvent-to-biomass ratio, thus promoting recondensation reactions of low molecular fragments obtained in the results of hydrolysis reactions of carbohydrates predominantly and increasing the nonliquefied portion of biomass (Jin et al., 2011).

In all tests, PEG 400-insoluble fractions exhibited notable composition differences compared to the crudeextract, see 'Figure 3a, b'.

The FTIR spectra of the crude BA bark extract and its PEG 400-insoluble fractions obtained under different conditions provide confirmation of the solubility of aromatic constituents in PEG 400 and the concentration of carbohydrates in the insoluble fraction 'Figure 3a'. This is evident from the decreased absorption at approximately 1500-1600 cm<sup>-1</sup> and 1260-1320 cm<sup>-1</sup>, which are attributed to vibrations of aromatic rings. Additionally, the absorption bands in the range of 800-1200 cm<sup>-1</sup> associated with cellulose and hemicellulose are increased in the spectra of the PEG 400-insoluble fractions compared to the crude extract.

The Py-GC/MS/FID data also revealed a significant increase in the content of aliphatic volatiles predominantly derived from carbohydrates, and a drastic decrease in the content of aromatic pyrolysis products, mainly derived from phenolic extractives, in all PEG 400-insoluble fractions compared to crude extracts, see 'Figure 3b'. Based on these results, we can conclude that, unlike the PEG 400-insoluble carbohydrates, the phenolic extractives of BA bark can be easier incorporated into PEG 400-based mixed polyol due to their better solubility in glycols, as opposed to carbohydrates. The increasing of biomass content in starting suspension resulting in non-complete liquefaction, leads to a more effective concentration of soluble phenolic components in polyols compared to the case when complete liquefaction of BA bark extractive occurred. These findings coincide with the results presented in (Kurimoto et al., 1999).



Figure 3. The different characteristics of crude extract versus fractions insoluble in PEG 400: FTIR spectra (a), and the ratio of sum peaks of aliphatic-derived compounds to that of aromatic-derived (average ±Std of three tests) in pyrolysis products of biomass samples according to Py-GC/MS/FID data (b).

We therefore assume that the soluble portion of BA bark extractives in PEG 400-based polyol can act simultaneously as a crosslinking agent and technical antioxidant in PU foam, thereby enhancing the thermal oxidative characteristics of the material. This study is still under development. Such parameters as dynamic viscosity, hydroxyl value (OHV) and residual water content are the principal characteristics of polyols usable for rigid PU foam obtaining. The polyols containing 15-25% of BA bark extractives completely liquified at 130°C-170°C were tested, see 'Figure 4a, b', (Table 2). As the concentration of the catalyst was in the range of 1-1.5%, the viscous stresses arising from polyol flow are linearly correlated with the deformation rate over time, allowing them to be characterized as Newtonian fluids, see 'Figure 4a'.



Figure 4. The Newtonian (a) and non-Newtonian (b) flow curves at 25°C for polyols vary based on the content of completely liquefied BA bark extractives, liquefaction temperature, and catalyst content.

Some increase in viscosity was observed with an increase in catalyst content up to 1.5% compared to that of 1% content (Table 2). The increase in catalyst content up to 3% results in a tenfold increase in polyol viscosity, which exhibits a trend of decreasing at deformation rate due to the degradation of their intrinsic structure, typical for pseudoplastic liquids (Table 2), 'Figure 3b'. Obviously, at high acid content, the shear of recondensation/repolymerization reactions inside the PEG 400-biomass system was

increased. Therefore, non-uniform products with higher viscosity were obtained.

For petroleum-derived polyols used for rigid PU foam preparation, the required values of OHV, viscosity, and water content have to be 300-800 mgKOH·g<sup>-1</sup>, below 300 Pa·s (at 25°C), and not more than 0.1%, respectively (Vieira *et al.*, 2011). The viscosity of all polyols containing completely liquefied biomass meets these requirements, being significantly lower than the critical value (Table 2).

Table 2

The characteristics of polyols on the basis of BA bark extractives liquific	ed
by PEG 400 under various regimes	

Liquefaction regime Biomess		Biomass	Characteristics of polyol			
T, ⁰C	Catalyst content, %	content in polyol, %	OHV, mg KOH∙g <sup>-1</sup>	Viscosity at 25°C, mPa·s	Water content (K.F), %	
130	1.0	15.0	192.7±29.0	630.0±35.0	0.35	
150	1.0	20.0	363.3±13.5	804.0±60.0	0.49	
170	1.0	25.0	318.5±10.0	1570.0±57.0	0.22	
130	1.5	20.0	391.8±12.0	1100.0±50.	0.32	
130	3.0	20.0	328.0±11.0	10700±720 (at 50 s <sup>-1</sup> )*	0.18	

The OHV of polyols containing 20-25% biomass increases by 1.2-1.5 times that of PEG 400 (280.5 mg KOH·g<sup>-1</sup>) but is lower than that calculated using the additivity principle, which takes into account the content of each component and it's OHV. This indicates the partial etherification of OH groups of biomass components by primary OH groups of PEG 400 in the presence of an acidic catalyst, resulting from alcoholysis reactions (Gosz et al., 2020). The residual water content in polyols was in the range of 0.18-0.49%, which does not meet the requirements of commercial polyols. This can be explained by the technical difficulties of removing traces of water from a comparatively polar system. In this case, the correction of isocyanate content in the PU foam recipes should be done taking into account two-step interactions of water with the isocyanate.

The results presented above indicate that the liquefaction of BA bark extractives proceeds according to the basic principles of lignocellulosic biomass interaction with polyhydric alcohols in acidic conditions. Together with the use of BA bark extractives, it allows for obtaining lower viscous polyols with a higher content of completely liquefied biomass (up to 25%) compared to polyols obtained based on wood, bark, and lignin (Jin *et al.*, 2011; D'Souza *et al.*, 2014; Gosz *et al.*, 2020). Tests of the obtained polyols in rigid PU foam compositions are under development.

## Conclusions

1. Two approaches aimed at introducing BA bark water extractives as building blocks in PU networks available for obtaining PU thermosetting films and rigid PU foam, respectively, were discussed. The fractions of BA bark water extractives insoluble in the THF medium used for PU elastomer synthesis exhibit an enrichment of carbohydrates compared to the crude extract. This suggests that introducing individual carbohydrate bark components into the PU elastomer structure is challenging and requires extensive modification.

- 2. Aromatic bark extractives, including those containing sugar units such as phenyl glucosides, can be utilized as biopolyols obtained under mild conditions. Liquid polyols of low viscosity containing up to 25% of BA bark extractives, completely liquefied by PEG 400 and therefore containing phenolic and aliphatic subunits, were obtained.
- 3. The relative content of polyphenolic and carbohydrate components of extracts in polyol can be controlled due to their rather differing solubility in PEG 400. Tests of the polyols obtained, including their antioxidative effect in the recipe of rigid PU foam, are under development.

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# A REVIEW ON SEMI TRANSPARENT SOLAR PANELS APPLICATION ON GREENHOUSE ROOFTOPS

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## Abstract

This paper provides an overview of recent progress reached in semi transparent photovoltaic systems (STPV), which are being assessed as a potential solution to enhance the productivity of plant grown in greenhouses. Utilizing this kind of renewable energy resources, relating with plant growing is attractive solution to increase sustainability for citizens. The aim of this study is to find out recent advances for application of various semi transparent photovoltaic systems which can be integrated in greenhouses. Solar PVs are among dependable, mature and cost-effective renewable energy systems and solutions, which are promising for building integrated photovoltaics (BIPV) application. The main emerging photovoltaic candidates for BIPV are amorphous silicon, kesterite, chalcopyrite, CdTe, dye-sensitized, organic and perovskite based systems. A monographic study approach has been utilized in this investigation, in ordain to compile and analyse the photovoltaic systems for BIPV mainly investigating and comparing two main parameters: average visible transmittance (AVT) and power conversion efficiency (PCE). The rapid development of new materials and structures for the manufacture of semi transparent solar panels allows a balance to be struck between AVT, PCE and a comparison of the reviewed materials indicates that organic and perovskite are the most promising for semi-transparent solar panel production and application in greenhouse constructions, based on their PCE and AVT results.

**Key words:** solar cell, building integrated photovoltaics, average visible transmittance, power conversion efficiency, semi transparent.

# Introduction

An attractive way to make efficient use of agricultural land and provide additional energy for crop production is to integrate photovoltaics into modern agriculture (Zhao *et al.*, 2021). Greenhouses are commonly constructed in open areas with high sunlight coverage, as sunlight is essential for plant photosynthesis. For this reason, such sites are always appropriate to produce PV (photovoltaic) power (Yano & Cossu, 2019).

The structure of a greenhouse is usually made of plastic, glass or fibreglass. This allows sunlight to enter the greenhouse and photosynthesize the plants. However, a key aspect is the use of electricity to power the greenhouse, i.e., the cooling, ventilation and irrigation systems in various climatic situations. Therefore, it is preferable to use a PV system to meet the power needs in greenhouses and provide a comfortable environment in the greenhouse, rather than consuming fossil fuels and exterior energy supplies to sustain this system (Lu *et al.*, 2022).

Solar PV is one of the dependable, mature and costeffective renewable energy systems and solutions. The International Renewable Energy Agency (IRENA) has forecast the worldwide installed capacity of PV by 2050 and found that PV could potentially contribute 4.9 gigatonnes (Gt) of emission (CO<sub>2</sub>) reductions in 2050. In Europe, installed PV power is expected to increase significantly to around 891 gigawatts (GW) by 2050 (International Renewable Energy Agency, 2019). The use of PV is also in line with opportunities for an urban energy transition in the city, as shown by a study on emission targets in the city of Riga. The transition to renewable energy sources will necessitate substantial material modifications at the household level, including the installation of PV or smart meters. Therefore, it is essential to comprehend individual and alliance values to prioritize low-carbon alternatives by citizens. This is a crucial aspect of urban energy strategies (Oliveira *et al.*, 2022).

The aim of this study is to find out recent advances for application of various semi transparent photovoltaic systems which can be integrated in greenhouses. To achieve the aim in the study, a monographic study approach was used in order to compile and analyse the photovoltaic systems for BIPV mainly investigating and comparing two main parameters: average visible transmittance (AVT) and power conversion efficiency (PCE).

#### **Materials and Methods**

The research employed a monographic study approach to compile and analyse photovoltaic systems for BIVP mainly investigating and comparing two main parameters: average visible transmittance and power conversion efficiency. This study summarises scientific literature from different publications and authors. Only articles from scientific journals extradited from 2004 were utilized, while more recent papers were preferred. To select and analyse 38 full text research articles and monographs Scopus, Web of Science, MDPI Science Direct and Google scholar research databases were used. The following keywords were used in the selection of scientific literature: amorphous silicon, kesterite, chalcopyrite, CdTe, dye-sensitized, organic and perovskite, semi transparent. For this review, multiple articles were analysed, and those that conducted research in a similar manner were selected.

#### **Results and Discussion**

The majority of agricultural industry is powered by non-renewable energy sources, such as fossil fuels, which are known to be greenhouse gas emitters that contribute to climate change and global warming. Growing concerns about the environmental impact of these non – renewable fuels tend to be alleviated by more sustainable resources (Bolyssov *et al.*, 2019).

Solar systems for building installation can be classified as Building-Added (BA) and Building-Integrated (BI) (e.g. facade-integrated systems, roof-integrated systems, etc.) (Lamnatou & Chemisana, 2017). The literature on greenhouse construction indicates a recent increase in interest in rooftop/BI greenhouses over the past five years. This includes rooftop/BI greenhouses with semi transparent PV cells that allow a certain percentage of solar radiation to pass through (Moreno *et al.*, 2023).

The co-cultivation of crops and photovoltaic energy production on the same space is referred to as 'agrivoltaics'. The term 'agri' pertains to the science and technology of crop cultivation, while 'voltaic' refers to photovoltaic energy (Gorjian *et al.*, 2022). In addition, rooftop greenhouses have the potential to create new agricultural areas in urban areas, using rooftops that would otherwise be unproductive. To optimise the energy needs of the buildings and greenhouses, this solution uses a building energy management system (Choi *et al.*, 2018).

While crystalline silicon (c-Si)-based units dominate the building integrated PV (BIPV) market, the opaque characteristics of silicon compose a significant potential for the introduction of new PV technologies that can achieve true semi transparency. These include: amorphous silicon, kesterite, chalcopyrite, CdTe, dye-sensitized, organic and perovskite based systems 'Figure 1'.



Figure 1. Classification of semi transparent solar cells for BIPV (Sun & Jasieniak, 2017).

Transparency is a crucial factor for BIPV applications. To reflect the sensitivity of the eye to different wavelengths, a parameter named average visible transmittance (AVT) has been implemented. It is computed as the average spectral transmission of visible light weighted by the photopic response of the human eye (1):

$$AVT = \frac{\int T(\lambda)P(\lambda)S(\lambda)d(\lambda)}{\int P(\lambda)S(\lambda)d(\lambda)}$$
(1)

In the calculation (Eq.1) of the AVT uses the ratio of the transmission ( $T(\lambda)$ ), the solar photon flux ( $S(\lambda)$ ), and the photopic response ( $P(\lambda)$ ) (de Bruin & van Sark, 2022). The power conversion efficiency (PCE) is another important manufacturing parameter. As shown in Equation 2, the PCE is the proportion among the electrical power produced by the side-mounted PV cell and the incident power:

$$PCE = \frac{P_{out}}{P_{in}} = \left| \frac{J_{mpp}V_{mpp}}{P_{AM1.5G}} \right|$$
(2)

where  $J_{mpp}$  – the current density at the maximum power point (MPP) of the cell;

 $V_{mpp}$  – the voltage at the MPP;

 $P_{AM1.5G}$  – the power of the incident AM1.5G spectrum (1000 W·m<sup>-2</sup> under standard test conditions (STC)) (de Bruin & van Sark, 2022).

#### Amorphous silicon

Amorphous silicon PV cells have an absorption coefficient that is one level higher than that of c-Si. Therefore, it is possible to reduce the thickness to the sub-micrometer range. For comparison, silicon solar cells typically have thicknesses in the range of hundred micrometers. This allows for tuning the required transparency. Hydrogen passivation is a critical step (in a-Si:H, where H stands for hydrogenation). The amount of hydrogen can also control the band gap. The higher band gap of 1.9-2.0 eV leads to higher visible transparency at the expense of lower short-circuit currents (Kumar *et al.*, 2023).

The use of germanium in the formation of amorphous silicon-germanium (a-Si0.8Ge0.2:H) has been investigated in a recent report (Lim *et al.*, 2013).

Such devices were conventionally grown from germane (GeH<sub>4</sub>) and silane (SiH<sub>4</sub>) in a partly hydrogenated conditions at 250 °C on a gallium-doped ZnO (ZnO:Ga) TCO. The p-i-n structure was used to fabricate the cells with ZnO: Ga serving as the top electrode. The appliance was fabricated with an active layer thickness of 150 nm to achieve transparency and demonstrated a PCE of 5.9% at an AVT of 17.9%. The comparison appliance lacking Ge achieved a PCE of 5.5% while maintaining a high level of visible transparency at 21.6% (Sun & Jasieniak, 2017). *Cadmium Telluride* 

A well-studied material is cadmium telluride (CdTe). It is II-VI semiconductor material with an outright band gap of 1.5 eV for single crystal and 1.42 eV for polycrystalline form. CdTe has high performance optical and electrical characteristics (Table 1). Thin-film modules, such as CdTe, have received considerable attention from the photovoltaic research community over the last two decades, consisting of

thin liner cells only a few micrometers thick. Small CdTe solar cells have improved dramatically in efficiency in recent years, from 16.5% to 22.1% (Wang *et al.*, 2018) and the general module productiveness for semi transparent PV windows are estimated to be in the diapason of only 4.1%-12% (Sun *et al.*, 2018). Additionally, in the wavelength range of 500 nm to 800 nm the average transmittance can be reached 14.21% (Xie *et al.*, 2024).

Table 1

Properties of CdTe				
Semiconductor	CdTe			
Crystal structure	Cubic			
Band gap	1.42 eV			
Lattice constant	6.482 Å			
Electron affinity	4.28 eV			
Absorption coefficient	104 cm <sup>-1</sup>			
Refractive index	2.76			
Density	5.85 g·cm <sup>-3</sup>			
Melting point	1092 °C			
Boiling point	1130 °С			
Young's modulus	$3.7 \times 10^{11} \mathrm{dyne} \cdot \mathrm{cm}^{-2}$			
Work function	5.7 eV			
Hole mobility	65 cm <sup>2</sup> ·Vsv <sup>-1</sup>			
Electron mobility	700 cm <sup>2</sup> ·Vs <sup>-1</sup>			

Source: Kapadnis et al., 2020.

#### Kesterite

A structural relative of chalcopyrite, kesterite  $Cu_2ZnSn(S,Se)_2$  (CZTSSe) and  $Cu_2ZnSnS_2$  (CZTS) have lately become viable competitors to  $Cu(In,Ga)Se_2$  (CIGS) absorbers due to their inexpensiveness, abundance on Earth and equally promising optoelectronic characteristics (Sun & Jasieniak, 2017).

Presently, the highest PCE for opaque CZTS appliance is 10.0%, with a short-circuit current density ( $J_{sc}$ ) 21.74 mA cm<sup>-2</sup>, open-circuit voltage ( $V_{oc}$ ) 0.7306 V including fill factor (FF) of 69.3%, and for CZTSSe PCE is 13.6%, with a  $J_{sc}$ =36.18 mA cm<sup>-2</sup>,  $V_{oc}$ =0.5375 V and FF of 69.8% (Green *et al.*, 2022). Due to their related lattice and energy transition structure to CIGS, kesterite-based technologies offer the benefits of an elevated coefficient of absorption (above 10<sup>4</sup> cm<sup>-1</sup>), a variable band gap energy ranging from an intrinsic of 1.0 to 1.5 eV, intrinsic p-type conductibility in a range appropriate for solar cells, and three-dimensional equality of carrier transport (He *et al.*, 2021).

While various technological applications are being investigated, there is currently no existing standard for kesterite technology although a standard exists for CIGS, which is the most similar material to kesterite. Furthermore, kesterite solar cells have been researched for many years, but only a few number of papers have presented stability values for this type of cell. (Larramona *et al.*, 2020). The researchers found that there was little or no initial loss of efficiency under continuous indoor irradiation and in outdoor field tests (Larramona *et al.*, 2020).

Chalcopyrite

A co-evaporation process was used in a single stage to produce semi-transparent thin-film solar cells with an ultra-thin Cu (In, Ga) Se<sub>2</sub> (CIGS) absorber layers were deposited on glass substrates coated with fluorinedoped tin oxide (Larramona *et al.*, 2020). Cu(In, Ga)Se<sub>2</sub> (CIGS) based devices have gained significant interest for thin film photovoltaic utilizing owing to their high absorption coefficient, tunable band gap, compositional tolerance, excellent stability and high efficiency (Kim & Shafarman, 2016). This is due to their tunable band gap of around 1.0-1.12 eV and high absorption coefficient of up to 105 cm (Mufti *et al.*, 2020).

Quantitative performance characteristics with different CIGS absorber thicknesses illuminated from both the front side and backside at a light luminance of 100 mW cm<sup>-2</sup> shown in Table 2.

Table 2

Characteristics of semi transparent solar cells with various CIGS absorber thicknesses

various crob absorber unemicsbes				
Absorber	Illumination	PCE,	AVT,	
thickness, nm	direction	%	%	
200	Front	6.89	18.53	
200	Rear	4.91	-	
300	Front	8.37	10.92	
300	Rear	6.25	-	
400	Front	9.75	5.06	
400	Rear	6.46	-	
2000	Front	14.89	0	
2000	Rear	3.29	-	

Source: Shin et al., 2021.

#### Dye-sensitized

Transparent solar cells, such as DSSCs, have received significant focus due to the flexibility offered by optical transparency and colour. Its inherent qualities, such as excellent low light performance and minimal angle dependence, make it suitable for BIPV (Chung *et al.*, 2020). While the manufacturing of DSSCs has been simplified, there has been an improvement in their PCE from 7% to 14%. DSSCs offer consistent performance in a variety of lighting conditions, including fluorescent and LED, strengthening their position in a variety of electronics applications, including wireless sensor networks, smart buildings, smart homes and wearable devices (Prajapat *et al.*, 2023).

Among TPV (transparent photovoltaic) technologies, DSSC technology has one of the greatest transmittance amount of solar radiation (Pulli *et al.*, 2020). Utilizing conventional red and orange dyes, the devices have been shown to achieve a solar transmittance of 20-30%, although using a chosen dye system that takes up light in the ultraviolet and near-infrared range, an astonishing transmission rate of 60% has been demonstrated (Barichello *et al.*, 2021). In recent solar cell efficiency tables, it can be found that PCE reaches 8.8-12.25% (Green *et al.*, 2022).

#### Organic

Fine organic particles or conductive organic polymers form the basis of organic solar cells (OSCs). Contingent on the power band gap of the light-absorbing element in the active layer, they can harness either higher-energy ultraviolet (UV) radiation or lower-energy infrared radiation and transform to electrical energy (Jain *et al.*, 2024). OSCs offer great advantages in terms of lightness, ease of manufacture, low cost and environmental friendliness compared to traditional silicon-based solar cells. Recently, PCE has increased from less than 3% to over 18% (Hu *et al.*, 2020).

In general, semi transparent organic solar cells (STOSCs) can be composed of a semi transparent active layer with a structure of transparent electrodes at the top and bottom, and show great potency in building windows, car windows and greenhouse roofs to meet human or plant needs (Han et al., 2021). Although semi transparent organic photovoltaics (STOPV) are not yet commercially available. The challenge of balancing device efficiency and AVT remains a topic of interest for researchers. Efforts are being made to increase efficiency to meet commercial standards while also optimizing AVT (Amin et al., 2023). The development of wide area STOSC requires increased transparency and a simple manufacturing operation as key industrial requirements. One solution is the fully solution processed IEICO-4F non-fullerene acceptor based STOSC with slot die coating, demonstrating 11% efficiency and 58% AVT (Ghosh et al., 2023). Perovskite

Perovskite cells (PSCs) are of interest to researchers around the world because of their high energy conversion efficiency, inexpensive materials and ease of manufacture (Srivishnu *et al.*, 2023). PSCs have excellent potential for large-scale industrialization in the near future due to the rapid growth of PCE from 3.8% to 25.5% and its low production costs (Chen *et al.*, 2022).

Perovskites are materials with an ABX3 crystal structure, and on this hybrid crystal structure, PCSs possess tunable bandgaps (1.3 - 2.2°eV), high absor-ption coefficient ( $5.7 \cdot 10^{40}$ cm<sup>-1</sup> at 600°nm), and a high degree of transparency (Noman *et al.*, 2024). Compared to a solar cell design, FAPb-I3 perovskite PV cell with the highest efficiency of 25.8% and power conversion efficiency of 0% has been applied in this PV cell, and FAPb-I3 perovskite PV cell has achieved efficiency of 15.1% and power conversion efficiency of 40%. Upon full dimensional parameter improving, the AVT can attain to 41.1%, 52.6%, 33.4% and 60.3% while the efficiency of FAPbI3 perovskite PV cell is 10%, 12%, 15% and 17%, appropriately (Zhou *et al.*, 2023). In recent solar cell efficiency tables, it can be found that PCE reaches 17.9 - 29.8% (Green *et al.*, 2022).

PSC has excellent commercial potential, but there are so many factors that need to be addressed. The efficiency of PSCs can be affected by several factors, including the prohibitive cost of gold electrodes, additives, temperature, moisture and UV illumination, degradation in the presence of oxygen, toxicity of lead, thermal stress, electrical bias, and interface. It is important to consider these factors when evaluating the result of PSCs (Sharma *et al.*, 2022).

In the case of the solar cells discussed in this article, it is evident that the majority of the evolving semi transparent categories now are at a commercial level, but from an aesthetic point of view, the colour and component construction need to be seriously rethought. Due to the non-unchanging absorption coefficient of absorbing films and the multi-layered nature of PV cells, the irradiance passing through the cells modify the spectral colours coordinates of the passing sunlight to a varying degree depending on the density of the absorber layer (Sun & Jasieniak, 2017).

# Conclusions

- 1. Comparing the reviewed materials, shows that the most promising materials for semi transparent solar panel production and application in greenhouse constructions could be organic and perovskite, due to the results achieved by their PCE and AVT.
- 2. With the rapid development of new materials and structures for the manufacture of semi transparent solar panels, it is possible to achieve a balance between average visible transmittance (AVT), power conversion efficiency (PCE), and design of construction, which allows to vary temperature, the intensity of the required light and the colour spectrum according to the goal to be achieved, in the same time fulfilling certain requirements of power needs.

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# DATA ACQUISITION SYSTEM FOR VEHICLE ENGINE SENSORS: A REVIEW

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# Abstract

Monitoring the operation of car engines using a smartphone and cloud services is a concept that falls within the field of intelligent vehicle technologies. Using information collection system, vehicle fleet companies can effectively manage the usage of their vehicles, minimizing investment and maintenance costs, preventing accidents and failures, identifying poor driving behaviour among employees, and reducing expenses associated with fuel, tires, and other resources. This approach involves collecting real-time data from the vehicle engine sensors, transferring data to the cloud via a smartphone, and then using cloud services to analyse and manage the information, making it understandable in a simple way. This review reflects on the working efficiency of internal combustion engines and the reduction of pollution to the environment, also gathers existing literature to gain insights into vehicle sensor data acquisition technology and systems in the automotive industry identifying gaps in current knowledge and provide a conceptual framework for next practical research in this field. After explaining the general idea of logistics tasks in technology development, various sensors and their methods are associated with engine properties are introduced. The research results show that most articles are about data acquisition systems from different systems. They can provide convenience and flexibility for users, allowing them to easily access and adjust settings on-the-go, enabling real-time monitoring and adjustment of engine performance, helping users optimize efficiency and performance based on their specific needs and preferences.

Key words: data acquisition systems, intelligent vehicle technologies, engine data collection.

#### Introduction

The continuous evolution and advancements in the automotive industry have propelled the sector forward, leading to improved safety standards, innovative technologies. Each decade brings new opportunities and challenges that drive the industry towards a future that prioritizes efficient, safe, and eco-friendly transportation solutions.

Every industrial processing system, factory, piece of equipment, testing ground, and automobile is made up of computer software and hardware that behaves in accordance with the known laws of physics. These systems are not steady state; instead, they are made up of thousands of mechanical and electrical phenomena that are always changing. A system's ability to operate correctly is contingent upon specific temporal events and variable parameters. Most variables need to be measured using a tool, like a visual display, that transforms the phenomenon into a form that humans can understand. Effective vehicle data collection is crucial for improving safety, efficiency, and overall performance in the automotive industry. It also plays a role in the development and implementation of emerging technologies such as autonomous vehicles and smart transportation systems (Oladimeji et al., 2023). Sensors in cars help drivers find problems with their car and prevent damage from happening. It can also display alerts for drivers and a reporting feature for remote diagnosis (Abdelhamid, Hassanein, & Takahara, 2014). They are essential for maintaining optimal engine performance, improving fuel efficiency, and addressing potential problems before they lead to more significant issues. Diagnostic tools and technologies continue to play a crucial role in modern automotive maintenance and repair. To overcome the limitations of existing communication technologies and create an efficient cooperative network for large-scale vehicular networks, alternative solutions need to be explored.

This may involve developing communication protocols specifically designed to handle the strong mobility impact and implementing cost-effective solutions that are suitable for vehicular environments. The in-vehicle controller area network (CAN) bus is a standardized serial communication protocol widely used in automobile internal control systems (Johansson, Törngren, & Nielsen, 2005). The integration of electronic devices in automobiles has significantly enhanced the driving experience by providing convenience, safety, and entertainment features. These advanced driving aids ensure better control over the vehicle and improved connectivity with external devices (Miller & Vasalek, 2013). The original point-to-point interconnection method was initially used, but the number of sensors and controllers in the vehicle has rapidly increased, making installation and maintenance more expensive. To optimize fuel efficiency and reduce greenhouse gas emissions, drivers can adopt several strategies by driving at a steady speed, avoiding unnecessary idling. By maintaining an optimal temperature range, the turbocharger compressor can function efficiently, enhancing overall engine performance (Olabi, Maizak, & Wilberforce, 2020). Under the anticipated Euro 7/VII standards, vehicle emissions are deemed to be generated by a singular, integrated system, with tailpipe emissions generally understood to be below the limit, irrespective of the technology package the powertrain comprises (Müller et al., 2022).

In order to find out the operation of the applied systems and the role of sensors in it, as well as to identify the characteristic problems for the further experimental research, the compilation of the results of different studies was carried out.

#### **Materials and Methods**

The study gathers existing literature to gain insights into vehicle sensor data acquisition technology in the automotive industry. By analysing the information available, the study will help identify gaps in current knowledge and provide a conceptual framework for researchers to explore new directions and opportunities in this field. The information that was published between 2005 and 2024 consisted of 40 fulltext research articles and databases. Several keywords such as data acquisition systems, intelligent vehicle technologies, engine data collection were used.

# **Results and Discussion**

Selecting the parameters to monitor is a crucial decision in any research related to vehicle engine performance, as it directly influences the quality and relevance of the data collected. Parameters includes selected vehicle engine sensors, data acquisition hardware such as an OBD dongle, low-power devices, cloud-based data transfer and displaying all information on a smartphone application for easy access and monitoring. Parameters during the operation of a vehicle engine allows for data collection, analysis, and optimization.

# Sensors

*Oxygen proportion in exhaust gases*. Maintaining the ideal ratio is essential as it affects various aspects such as engine performance, emissions, consumption, and the lifespan of the catalytic converter. By preventing issues like engine pinging and knocking ideal ratio ensures optimal engine functioning and reduces harmful emissions.

*Engine coolant temperature* is measured by the Engine Coolant Temperature (ECT) sensor. It sends a signal to the engine control module, which activates other components to maintain proper operating temperature. The lambda sensor, on the other hand, takes over and measures the oxygen in the exhaust gases to help regulate the fuel mixture for ideal combustion once the engine reaches operating temperature. This is important because the engine`s temperature plays a crucial role in preventing overheating, which can negatively impact the engine`s lifespan and increase of emissions.

*The vehicle speed* is measured by Vehicle Speed sensor (VSS). Usually, it is installed on the output shaft of the gearbox. It measures the speed of the vehicle and sends this information to the engine control unit (ECU), where the gathered data on the speed of the vehicle is calculated to parameters like fuel injection timing, transmission shift points, and ABS activation. This information helps optimize fuel consumption and reduce emissions by determining the relationship between vehicle speed and fuel consumption.

The *air flow* is measured by the Mass Air Flow (MAF) sensor. A malfunctioning MAF sensor can lead to a decrease in engine efficiency and performance. It can cause the engine to run rich at idle, meaning it will use more fuel than necessary. This can result in poor fuel efficiency and increased emissions.

The *ignition pickup* sensor plays a vital role in the ignition system by accurately detecting the

distributor's shaftposition, allowing the engine control module to effectively manage ignition timing for optimal engine performance. Failing to address issues with this sensor can result in significant problems like engine misfires, stalling, and difficulty starting. Regular maintenance and timely replacement of faulty sensors are essential for smooth engine performance. The *throttle position sensor* measuring the angle of the throttle plate or lever and transmitting this data to the ECU. By adjusting the throttle, the driver can control the speed and power output of the engine by regulating the amount of air and fuel mixture entering the combustion chambers. This mechanism is crucial for maintaining fuel efficiency and performance in gasoline engines. The proper air/fuel mixture is essential to the combustion process, which places strict demands on the accuracy of the throttle position sensor.

The *knock sensor* purpose is to detect engine knocking or pinging caused by improper combustion in the engine cylinder, which can lead to damage. By monitoring these vibrations and sending signals to the engine control unit, the knock sensor helps adjust ignition timing to prevent knocking and ensure smoother engine operation. Its placement on the engine block, cylinder head, or intake manifold allows it to effectively detect these vibrations and contribute to overall engine performance and longevity.

The *Manifold Absolute Pressure (MAP) Sensor* helps the engine control unit adjust the fuel injection volume based on the changing intake manifold vacuum levels at different engine speeds and loads. The engine control module uses this pressure reading to calculate the amount of fuel that needs to be fed to each cylinder and the timing of the ignition. By converting these vacuum variations into voltage signals, the MAP sensor ensures the correct fuel-air mixture for optimal engine performance.

The *Exhaust Gas Recirculation (EGR) position sensor* play crucial role in monitoring and controlling the exhaust gas recirculation process in a vehicle's engine and helps in determining the exact position of the EGR valve pintle. By accurately controlling the opening time and duty ratio of the valve, the system can efficiently manage the recirculation process to minimize emissions and enhance the engine's performance (Rimpas, Papadakis, & Samarakou, 2020).

#### Data collection and processing technologies

Many researchers have made significant efforts to analyze and collect various aspects of vehicular data. Some have focused on gathering data related to vehicle performance, such as fuel consumption and emissions (Olabi *et al.*, 2020). Some scientists from Israel and Australia (Grimberg, Botzer, & Musicant, 2020) reported a review on prospective technological advancements that could have more effects on the use of smartphones to research and improve road safety, while Guardiola *et al.* (2021) states that Determining inservice emissions at the vehicle and fleet levels appears to be a significant advancement for the upcoming generation of vehicles thanks to a clever integration of embedded and cloud components. Also, there have been efforts to collect data on traffic patterns and congestion (Celesti *et al.*, 2018), data related to autonomous vehicles and their interactions with other vehicles and infrastructure (Zhou, Li, & Shen, 2019). Mesenger *et al.* (2017) presents the architecture, which adopts data mining techniques and neural networks.

Table 1 shows Kumar & Jain (2023) suggested approach which classifies driver behavior using machine learning techniques based on ten categories: fuel usage, braking patterns, steering stability, and velocity stability. Also, contrasted with commercial driver and automobile tracking programs Campos-Ferreira *et al.* (2023) is based on basic algorithms and makes use of traditional sensor measurements.

In 'Figure 1', Malekian et al. (2017) developed a

comprehensive system for monitoring and analysing land vehicle fleets.

There are several different devices based on OBD-II and paired with adapters, allow users to access and monitor engine data directly from their connected software. It is important to carefully evaluate pros and cons, determine which one best fit the specific needs. These systems typically consist of hardware components for signal conditioning and analog-todigital conversion, as well as software for data processing and visualization. The specific choice of system will depend on factors such as the number of sensors, type of data being collected, and required level of precision, speed, cost, scalability, ease of use, and integration capabilities. Examples of a data acquisition systems for acquiring data from a sensor array are described below.



Figure 1. The subsystem functional units.

#### On OBD-II based data acquisition

On-board computers in modern cars only provide the driver with specific information. Most of the data is only accessible from specialized service stations. This highlights the complexity of decoding the messages sent by vehicles, as manufacturers often utilize their own unique encoding schemes that may differ between vehicle models. This variability adds an extra layer of challenge for those looking to interpret and understand the data transmitted by vehicles (Balakrishna, Thirumaran, & Solanki, 2018).

OBD-II modules are commonly used in monitoring tools to access data from the ECU of vehicles. By tapping into the vehicle's onboard computer system, these modules can provide real-time information on various vehicle parameters like speed, engine RPM, fuel consumption. This technology allows for consistent and reliable collection of information for analysis and diagnostics. The OBD interface acts as a crucial point to accessing vehicle sensor data by offering a standardized means of communication and discovery for various sensor readings. By providing a common platform for accessing information in a uniform format, it streamlines the process of extracting specific data points and facilitates compatibility across different vehicle models (Silva *et al.*, 2018).

Overall, OBD-II system serves as a gateway to the Controller Area Network (CAN) within a vehicle, providing access to limited data from various sensors. These sensors transmit messages with their current measurements over the CAN, but the information is often encoded in a manufacturer-specific format that may differ between vehicle models (Matesanz et al., 2021).

Reininger *et al.* (2015) was one of the first who introduced a vehicle data collection system using an OBD-II dongle. Aljaafreh *et al.* (2011) presents a system that collects information about cars and uses OBD, GPS, and Wi-Fi to manage them automatically. Moreover, researchers present to optimize route planning for taxi drivers using OBD-II that would minimize fuel consumption and decrease vehicle emissions (Ding *et al.*, 2017). Higher level combinations of various data sources can also be achieved by combining data from smartphones and current telematics systems (Rehrl *et al.*, 2018).

Matesanz *et al.* (2021) showcased the potential for modern mainstream cars to be transformed into a global sensor network through the deployment of software. Having sensors supplied from different producers with varying data-access channels can complicate data collection and integration processes. This achievement not only highlights the capabilities of current automotive technologies, but also suggests the scalability and adaptability for other automakers or operators with large sensor networks to take advantage of this technology. *Arduino data acquisition system* 

It's an electronic platform that allows users to create projects by connecting various inputs and outputs. It offers a wide range of possibilities, from recording data to controlling motors or LEDs, and even connecting to the internet. The hardware and software are easy to use, making it accessible for both beginners and experienced users. Data acquisition is comparatively inexpensive, the software is open source, and programmers find it easy to work with the abundance of freely available online libraries. It also boasts excellent durability and dependability (Fuentes et al., 2014) even when used in harsh environments such as that of the vehicle. Additionally, Arduino boards provide an affordable and accurate means for users to learn measurement procedures, making it an excellent tool for training purposes (Vidal-Pardo & Pindado, 2018).

Authors of another study used Arduino to create an affordable, high-performing data acquisition system for dual-fuel engine research (Sinaga *et al.*, 2019).

#### The Internet of Things (IoT) data acquisition system

It enables the connection between virtual and physical objects through intelligent devices, allowing for communication and actuation capabilities (Paudel & Neupane, 2021). The IoT consists of various objects that offer specific information, data, or services: from basic devices like digital cameras to more comprehensive entities like our homes, offices, daily surroundings, or vehicles (Kim, Oh, & Kang, 2017).

The utilization of data collected in real time from various electronic devices within vehicles and infrastructures has become crucial in analysing and understanding the dynamics of traffic, infrastructure operation, and overall system performance. By tapping into this data through advanced information and expert systems, organizations can make informed decisions, optimize operations, and improve safety and efficiency in the transportation sector (Ang *et al.*, 2019).

Pourrahmani *et al.* (2022) states that each object within the IoT ecosystem serves to provide its unique set of functionalities and capabilities In order to help the car navigate more quickly, the developed IoT system can gather a variety of data using the most precise sensor devices (Prinsloo & Malekian, 2016), traffic monitoring (Celesti *et al.*, 2018), but Brous *et al.* (2020) approaches the issue of IoT adoption in different domains, namely water management and road management.

#### Rasberry Pi data acquisition system

The Raspberry Pi is a single-board computer and runs on the Linux operating system. It serves as a central controller for various data sources, collecting data from sensors through a Python script. The results confirm that the performance of developed system is comparable to some higher-priced and less portable data acquisition systems (Ambrož, 2017). Also, data can be stored in a MySQL database, reducing memory usage, and improving reliability (Andria et al., 2016). Aciti et al. (2018) described as a prototype vehicle data capture and monitoring system that enables the user to observe the on-board system and get the vehicle's geolocation via GPS-enabled satellite monitoring. It appears that the system integrates a software component with a vehicle platform to collect sensor readings, which can be transmitted in real-time or as trip records with specific consistency guarantees in recorded files. This setup allows for access to acquired data through a cloud platform, enabling efficient data management and analysis for various automotive applications.

Influencing factors and future perspectives

Cyberattacks on the in-car network and dongle exploitation pose a threat to OBD-II ports. As they permit the gathering of diagnostic data, access to the in-car network, and the installation of malware, OBD-II ports are vulnerable points in automotive security. El-Rewini *et al.* (2020) review a valuable insight into the various attacks and threats targeting the communication layer, along with effective countermeasures to mitigate these risks.

Additionally, the scanners or applications can access a wealth of information, ranging from engine performance metrics to emission levels. In the case of a vehicle, locating and modifying a dependable power source can present challenges (Aciti, Urraco, & Todorovich, 2018).

Sensors presents a significant challenge as it leads to limited power availability from energy sources. This constraint requires a careful balance between sensor size, energy consumption, and overall system efficiency. To successfully overcome this challenge, researchers and developers need to explore innovative approaches to power management and energy harvesting techniques to ensure effective and sustainable operation of these sensors in various applications (Raj & Steingard, 2018).

Table 1

Summary of selected studies with data acquisition type, the indices, results					
Authors	The goal	Applications/Devic es/Techniques	Indices	Results obtained	
(Kumar & Jain, 2023)	To assess the performance of a platform that was receiving actual data streams from moving vehicles	Machine learning techniques (SVM, AdaBoost, Random Forest)	<ul><li>Fuel consumption</li><li>Steering balance</li><li>Velocity balance</li><li>Breaking archetypes</li></ul>	99%, 99%, and 100% of 3 different models with associated learning algorithms	
(Reininger et al., 2015)	To create a prototype for a mobile computing platform that enables users of smartphones and tablets to access vehicle sensors	ELM327 WiFi Smartphone Sensor	<ul><li>Fuel consumption</li><li>Engine RPM</li><li>GPS location</li><li>Speed</li></ul>	Driving behaviour analysis can benefit from the use of data collection and visualization tools	
(Osman & Massoud, 2013)	To construct a customizable, low-cost DAS with sensors, an analog to digital card, and an acquisition and processing software package	A/D boards and RS232 devices	<ul> <li>Pressure of the cylinder</li> <li>Cylinder block vibration</li> <li>Temperature of oil, inlet and outlet water</li> <li>Crank angle</li> <li>Engine`s RPM</li> </ul>	After processing the collected data, the system calculates the average cycle over the course of the four strokes as a function of a synchronized crank angle	
(Andria <i>et</i> <i>al.</i> , 2016)	To make a low-cost acquisition platform to gather information about vehicles that can be used for things like tracking drivers, managing vehicles, and finding problems.	Raspberry Pi, IMU, ELM327 device, GPS receiver	<ul><li>Vehicle speed</li><li>Engine RPM</li><li>Vehicle acceleration</li></ul>	Showed two clearly distinct behaviours, which can influence fuel consumption, car reliability and more generally, driving security	
(Malekian <i>et al.</i> , 2017)	To track and analyze vehicles by measuring their distance traveled, speed, and fuel consumption	ELM327 integrated circuit Interface protocols (CAN, ISO) Wireless communication module GPS tracking	<ul> <li>Speed</li> <li>Mass air flow (MAF)</li> <li>Distance</li> <li>Fuel consumption</li> </ul>	The system can successfully process, send, and display the readings in addition to reading a variety of parameters	
(Campos- Ferreira <i>et</i> <i>al.</i> , 2023)	To display in real time the relationships between fuel consumption, exhaust-gas emissions, driving style, and driver health	A biometric wristband, a smartphone, and an on-board diagnostic connector	<ul><li>Polluting emissions</li><li>Fuel economy</li><li>Driving behaviour</li><li>The health of the driver</li></ul>	The index of fuel consumption 84%, the emissions of pollutants 89%, and the driving style 89%; there are findings about the relationship between the driver`s heart and traffic conditions	
(Bedretchu k <i>et al.</i> , 2023)	To develop an intelligent, low-cost, IoT-based system for gathering vehicle data while conducting on-road testing	A low-cost acquisition hardware with an IoT server artificial intelligence (AI) algorithms	<ul> <li>Uploaded data</li> <li>Update rate</li> <li>Engine speed</li> <li>Vehicle speed</li> <li>Vehicle consumption</li> </ul>	System delivers data performance rate at 13 times cheaper; hardware processes and updates the server with all collected data at a rate of 330 kB s <sup>-1</sup>	

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The order of the characteristics in Table 1 would affect whether or not data collection methods are appropriate for use as research instruments in various fields. Affiliation with applications (2nd attribute in the table) and indices (e.g., engine parameters and use of data), would be crucial in the researcher's selection of the effective data acquisition method. Depending on the study, researchers may find many more implications beyond those listed in Table 1, such as cost implications, independent battery, and storage capacity.

However, in terms in ecological solutions, embracing sustainable practices in data analysis and monitoring can lead to significant reductions in carbon emissions and resource consumption, contributing to a greener automotive industry. Implementing extensions such as capturing more metrics of the vehicle engine, like vehicle wear, average fuel consumption, and reduction of exhaust-gas emissions.

At least some storage capacity is essential to ensure that all gathered data is captured and retained for analysis and future reference. Without this capability, valuable information may be lost or inaccessible, potentially impacting the overall success and reliability of the data acquisition process.

The lack of emphasis on the data-collection process in existing papers might be due to researchers prioritizing the application and functionality arising from data acquisition. Consequently, scientists typically choose for logging and uploading data when Wi-Fi is accessible (Pese, Ganesan, & Shin, 2017). To achieve seamless connectivity, it is crucial for technology to make significant advancements in terms of speed and computational capabilities, as well as ensuring a highly reliable connection. This will allow for easy integration of vehicles with any devices, providing users with a smooth and efficient experience (Apostolos Papathanassiou & Khoryaev, 2017).

In general, it is necessary to consider various types of problems in the operation of the previously discussed systems and cooperation with sensors. For example, the system power could shut down during vehicle engine turning based on loss of wireless communication and GPS location tracking.

A primary advantage of remote diagnostics, is that the expert can react immediately to measurement results, conduct additional measurements, modify parameters, and address actuators. By monitoring vehicle engine key metrics and making necessary adjustments, users can ensure that their engine operates at peak performance levels, ultimately saving time and resources. This access capability also illustrates the significant difference between remote diagnostics and the approach of using a logger or on-board tester. By embracing advanced technologies such as cloud storage and data analysis, can gain a competitive edge by harnessing real-time insights from engine data. This proactive approach not only enhances operational efficiency and maintenance practices, but also can be used from private practices to large scale fleet demands for their sensor readings and strengthens customer engagement through the delivery of valuable information using user-friendly smartphone applications. After consolidating these researches, it comes down to development an efficient and userfriendly application for data acquisition that can be easily installed, readable and self-sufficient.

# Conclusions

- 1. Advances in technology over the last decade have made it possible to significantly improve engine control and management, introducing major innovations such as remote diagnostics and cloud storage.
- 2. The wide range of sensors allows obtaining a valuable amount of information, but there are significant gaps, for instance, it is possible for different manufacturers to supply the sensors themselves with different data-access channels.
- 3. Data collection and processing technologies still face certain challenges as lack of standardization, data security and storage.
- 4. During creation of own system, attention should be paid to the analysed engine signals, data transfer to the cloud and creation of smartphone application, which is also confirmed by various researchers in the development and testing of their own systems.
- 5. Predicting future technology development in the context of the development of your own system, it would be necessary to pay additional attention to enabling real-time remote control capabilities for engine sensors in addition to only monitoring them.

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# THE DEFORMATION MONITORING SYSTEM ON THE BRASA OVERPASS IN RIGA

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#### Abstract

Engineering structures such as bridges, overpasses, and viaducts constitute a crucial component of the infrastructure of any industrial city. The wide-scale industrialisation of the twentieth century transformed the urban landscape. Many designs and solutions have become morally and physically outdated since those times, yet their usage continues, which is not always safe. With the aging of infrastructure, the issue of their further safe use inevitably arises. Geodetic monitoring of structural deformations can provide control and safety, as well as gather data for designers and engineers. The data collected by deformation monitoring systems should form the basis for the reconstruction and maintenance project of infrastructural facilities. Deformation monitoring systems are designed for each object based on the parameters of the structure, taking into account the constructive features, materials, and the importance of the infrastructural object to the city traffic. It is not always possible to completely close an overpass during reconstruction, as this would affect the transport flow in a specific district of the city. Monitoring of recently put into operation structures will ensure the collection of deformation data for the survival analysis. Once the structural health is defined, the period of service life until scheduled maintenance will be determined. As a result of our research on the Brasa overpass in Riga, we developed a scheme for swift response to signals from the monitoring system's sensors. Additionally, we ensured the safe operation of the old overpass during the construction of the new one by promptly utilising data obtained from the deformation monitoring system.

Key words: deformation monitoring, geodesy monitoring, accelerometers, inclinometers.

#### Introduction

Deformation monitoring systems are becoming increasingly popular in Europe and globally (Zhang & Broere, 2023). During the design and construction phases, many structures are now integrated with safety systems based on deformation monitoring (Shardakov et al., 2023). In such structures, such as the roofs of public buildings, safety systems are essential, due to not only the potential ageing of the structure but also additional loads caused by weather conditions, such as snow (Tsvetkov et al., 2017). Deformation monitoring is also mandatory in structures with increased danger to the population, for example, reservoirs and dams of power stations. The collapse of such structures could lead to incredible destruction (Chrzanowski & Szostak-Chrzanowski, 2009). Currently, in Latvia, there is no widespread use of deformation monitoring systems, as it is not mandatory and not stipulated in legislation. Nevertheless, there are successful examples of such technology application in Latvia, indicating an interest in the use of such systems and suggesting that the demand for deformation monitoring will continue to grow and evolve over time (El-Din Fawzy, Kandeel, & Farhan, 2023).

One significant example of the application of deformation monitoring is the Brasa overpass. In 2023, the reconstruction of the Brasa overpass in Riga was completed. Initially, a reconstruction of the old overpass was planned, but a deeper structural surveying of overpass revealed that it did not meet safety requirements. The project client set specific objectives for the designers. Firstly, to develop a deformation monitoring system for the old overpass, and secondly, to design a system and protocol for responding to deformations that exceed acceptable limits. Engineers and builders were faced with the task

of organising the safe operation of the old Brasa overpass during the construction of a new structure at the same location, as the overpass was a very important part of Riga's infrastructure. For this purpose, a deformation monitoring system was developed. The system included methods such as geodetic surveys at certain intervals, as well as continuous 24/7 monitoring with sensors attached to the structures of the old overpass. The monitoring system also included an alert system for responsible persons and a video monitoring system.



Figure 1. Half of old Brasa overpass, and pail drilling for new construction.

For the construction of a new overpass, there was no available space, necessitating the erection on the site of the old overpass 'Figure 1'. This entailed a singular approach: dismantling the old overpass in two phases. Following the removal of the first half, construction of the new overpass commenced, whilst tram movement was maintained on the remaining half. The Brasa deformation monitoring system installed on the overpass ensured the safe passage of public transport across the old structure, albeit in a reversible mode facilitated by traffic lights. The necessity for this system was twofold: not only was the old overpass in a state of disrepair, but the structural integrity was further compromised by the partial dismantlement of the bridge's construction along its axial line.

**Materials and Methods** 



Figure 2. Overpass plan with monitoring points.

The company LLC (Limited Liability Company) 'Tiltprojekts' tasked with monitoring was deformations on the Brasa overpass. For the assessment of the bridge condition, methodologies such as geodetic monitoring were employed, encompassing monthly inspections by a surveyor of specific points using a total station, in addition to the implementation of continuous monitoring via sensors (accelerometers, inclinometers). For reporting purposes, photo fixation files were generated using a camera with a 360-degree capture angle to document changes in the structure (emergence of new cracks), while existing cracks were selectively filled with a gypsum solution to monitor the progression of their expansion. 'Figure 2' illustrates the overpass plan with monitoring points indicated, different types of sensors, geodetic marks, as well as the gateway internet connection site for data collection, processing, and transmission to responsible parties are distinguished by various colours.

Dimensional parameters, obtained by surveyors from the old overpass, along with the available original drawings of the overpass, formed the basis for the creation of a 3D model. The model incorporated the reinforcement parameters and materials from the original drawings. Utilising computer software and the model, the loads that the old, worn structure of the overpass could withstand were calculated, as well as what the safe limits of structural deformations would be. Utilising the data acquired during tram tests, permissible speed regimes for public transport movement, as well as standard deformation values for the bridge's span structures, were calculated.

Should these permissible values be exceeded, an alert system was activated. 'Figure 3' displays the block diagram of the emergency response system. An alarm signal was sent via SMS and duplicated to various engineers to mitigate the risk of unavailability or preoccupation of any specialist, thus eliminating the human factor. In the event of adverse circumstances, a stop signal from the traffic light was to be activated, halting movement across the old overpass. Additionally, notifications were dispatched to responsible services, including the railway. By closing tram traffic and removing the load on the spans, the safety of train movement beneath the overpass could be guaranteed.

Each month, the surveyor examined geodetic marks to analyse the subsidence of structures. A total of 112 reflectors were installed on the supporting structures of the overpass to monitor long-term subsidence and deformations. Through geodetic monitoring, weak points on the beams and supports were identified, where the subsidence was consistently increasing and exceeded the precision of the instrument. These areas received increased attention, and some precise sensors were relocated to these weak points for more detailed study and improved deformation control.



Alert system algorithm

Figure 3. Alert system algorithm.

#### **Results and Discussion**



Figure 4. Diagrams from experiment with tram speed.

An example of sensor reporting is depicted in 'Figure 4'. These deformation graphs were obtained during the testing of the entire system by operating trams in various directions at different speeds. Through this experiment, a safe speed regime for trams was established, which did not induce critical deformations in the span beams. Trams were strictly prohibited from exceeding a speed of 30 km/h. Occasions occurred during operation where drivers exceeded this speed limit, imposing additional load on the structure, which was recorded by the system and, in conjunction with video surveillance, violators were identified and subjected to sanctions.



Figure 5. Deformation of the overpass span beam.

Geodetic measurements using a total station revealed deformations in the central beams following the dismantling of half of the overpass. It can be assumed with high probability that the cross ribs of the beam structure provided stiffness to the entire span. After the demolition of half of the structure, the central beam assumed the role of the outer beam, lacking the stiffness provided by the lost ribs, as illustrated in 'Figure 5'. Consequently, surveyors were compelled to supplement their survey with monthly levelling of the tram rails to ensure that the span structure did not continue to deform.

During the summer period, amidst high solar activity, maximum deformations were reached at one instance, rendering the overpass operation hazardous. Following all stages from the block diagram, engineers decided to halt traffic across the old overpass. Immediate analysis of the data was undertaken. Recalculation of permissible deformations at high temperatures indicated that the threshold for critical deformations also shifts with temperature changes. Two days later, traffic was reopened on the overpass after adjusting the critical value levels according to the ambient environment. Other similar studies on deformations in comparable climatic conditions, characterised by sharp temperature fluctuations, encountered similarly rapid increases in the deformations of concrete structures.

As a result, the system was so well calibrated and configured that the operator monitoring the deformations noticed a minor surge in deformation. These surges coincided with the passage of the same tram over the overpass. Upon deeper inspection, it was calculated that the front axle on the right side of the tram had a defect, causing additional load on the spans. This tram was removed from service and sent for suspension repair.
#### Conclusions

1. Contemporary structural health monitoring (SHM) methodologies for engineering edifices can render their utilisation safer for society, in addition to enhancing the predictability of structural wear for designers during restoration works. The successful implementation at the Brasa overpass serves as a paradigm that ought to be applied in other urban infrastructure repair and construction projects. The monitoring system can be scaled to accommodate any size of structure. Geodetic surveys conducted with traditional methods, such as total stations, fail to provide comprehensive data regarding the health of structures. Thus, the combination and integration of various deformation monitoring methods enable the provision of reliable control over aged structures. These methods complement and provide mutual support to one another. Monitoring systems, predicated on high-precision

sensors, are capable of surveilling the condition of a structure 24/7, thereby implementing a significant advantage over alternative methodologies. The capability to connect sensors to the internet facilitates the prompt transmission of data to responsible services, allowing for informed decisions regarding the further exploitation of the structure under study.

2. Our research could serve as a foundation for the development of legislation in Latvia, mandating the monitoring of old structures that are in use during repair works. Such measures enhance public safety. In future research, we aim to reduce the response time to emergency situations by connecting the monitoring system to traffic lights. This integration would immediately close the overpass upon receiving a signal indicating that the permissible deformation limits have been exceeded.

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# ROBOTIC PROCESS AUTOMATION IN SMALL AND MEDIUM ENTERPRISES – A REVIEW

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#### Abstract

Robotic process automation (RPA) is relatively new software technology that is quickly being adopted by companies around the globe to free office workers from routine, monotonous and rule-based tasks letting them invest their time in higher complexity and value tasks. While big companies have money, time and workforce resources to implement RPA, small and medium enterprises (SME) fall behind in their effort to start using RPA despite the fact that for this segment of organizations RPA would be useful as it presents the opportunity to re-arrange their limited resources and delegate part of work to software. To address this situation, the aim of this paper is to conduct systematic review of literature regarding RPA appliances in enterprises in order to find out how to implement RPA successfully, what processes to give to RPA, and how SMEs can implement RPA better. During the review main guidelines on how to implement RPA in enterprise in general and which processes to delegate to RPA in particular were identified as well as challenges RPA implementation might bring to company. It was also noted that there is missing research on how to adopt RPA specifically in SMEs segment. The conclusion is that SMEs aimed RPA implementation guidelines are missing.

Key words: robotic process automation, small and medium enterprises.

#### Introduction

Robotic process automation (RPA) is a software that literally replicates human actions on computer following the same rule based routine tasks like moving the mouse around the screen, clicking on buttons, links, etc., reading and writing data across different applications desktop or web or else, doing calculations, moving or creating files, interacting with PDFs and other document formats, using optical character recognition (OCR) and other technology.

In 2023, there were around 24.4 million small and medium enterprises (SME) in the European Union (EU) employing around 85 million people and creating half of the value added to EU's economy. Out of those enterprises one third have adopted one basic digital technology, one fourth said they need advanced digital technology and have adopted it, one tenth considers the adaptation of advanced digital technology but 8% of SMEs haven't adopted anything due to lack of knowledge or financing (Statista, 2023).

In a meantime, the so-called Digital Transformation (DT) is having huge importance for companies across all spheres of work because it changes the relationship with customers, suppliers, human resources and the creation of value (Zaoui & Souissi, 2020). And when SMEs stay behind the curve, competition with advanced SMEs and bigger companies just get tougher.

The usage of RPA in organizations has rapidly increased in recent years and is projected to grow in the foreseeable future by 20-30% per year. The implementation of RPA as per expectations will increase productivity by 86%, quality by 90% and reduce office costs by 59% (Denagama Vitharanage *et al.*, 2020; Choi *et al.*, 2021; Axmann & Harmoko, 2021).

Considering the RPA potential, it is important to understand how to apply the RPA to SMEs, which processes to give to RPA, to what challenges enterprises should prepare before implementation of RPA, how to prepare workforce for the coming changes. To address these issues, this paper conducts a systematic review of literature regarding RPA in enterprises in first part doing bibliometric analysis in order to understand main keywords, publishers and authors in the field, in the second part content analysis is conducted in order to understand what is found in current literature about questions concerning this topic.

#### **Materials and Methods**

This systematic review of RPA in SMEs includes both bibliometric and content analysis. The analysis process has been shown in 'Figure 1' and follows the approach designed by Liu *et al.* (2021).



Figure 1. Phases of systematic review.

For this study the Web of Science database was used. The search criteria for topic were 'robotic AND process AND automation AND enterprises', period was from 2008 when higher volume of publications start to appear until 2023, and paper types were article and review.

This way 138 articles were found.

Using CiteSpace (Chen, 2006) software the network map of the most influential journals, authors and keywords in the topic were drawn.

Secondly, answers to questions that are important to be answered in order to understand the situation of RPA in SMEs were searched for:

RQ1: What are the features of successful RPA implementation?

RQ2: How to determine RPA fit process?

RQ3: What are the challenges of RPA adoption?

RQ4: What are the gaps in research?

#### **Results and Discussion**

*Bibliometric findings* Research on RPA had a single publication each year starting from 1999, but it ramps up from 2008 having 2019 and 2021 as the most published in years 'Figure 2'.



Figure 2. Annual publications on RPA in enterprises topic.

This increase of academic interest in the topic and following articles can be explained by the growing appliance of RPA. Industry well known main RPA vendors were founded in the beginning of 2000's – Blue Prism in 2001, Automation Anywhere in 2003, UiPath in 2005, fulfilling demand for RPA and the industry went up from there.

Content analysis



Figure 3. Most influential journals.

Drawing on the co-reference analysis the most influential journals on the topic were found as seen in 'Figure 3' (Computers in Industry, 2024; Lecture Notes in Business Information Processing, 2024; IEEE Access, 2024).

Similarly, the most influential authors were found to be S. Aguirre, D. Fernandez and S. Anagnoste as seen in 'Figure 4'.

Aguirre has one very cited article (Aguirre & Rodriguez, 2017) which is one of the first use cases documented in literature hence the popularity and many citations.

Anagnoste's most cited article by far is about how RPA can improve the work of back-office operations (Anagnoste, 2017).

Most cited article by Fernandez is also published at the beginning of the RPA research popularity surge and just like previously mentioned articles this early publishing made them very cited across later papers (Fernandez & Aman, 2018).



Figure 4. Most influential authors.

Finally, most popular keywords in the topic were found out similarly and include DT, artificial intelligence, industry 4.0, framework, design to name a few as seen in 'Figure 5'.

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Figure 5. Most popular keywords in the topic.

*RQ1:* What are the features of successful *RPA* implementation?

While analyzing the selected articles, it became clear that independently of enterprise's size, industry and other factors, there are common approaches that lead to successful implementation of RPA.

Enterprises tend to follow a 4 or 5 stage implementation framework where 4 staged one is the

most popular – identifying process, defining AS-IS to TO-BE, then followed by bot development and the monitoring of actions (Huang & Vasarhelyi, 2019). 5 staged framework is basically the same but includes testing stage in it (Gex & Minor, 2019).

Before starting with RPA regular practice is to do proof of concept (PoC) process, where with specially selected process desired RPA tool is tested so that it is what a client thinks to avoid later disappointment as a law low complexity, high volume and value processes are preferred (Gex & Minor, 2019; Lacity, Willcocks, & Craig, 2015; Flechsig, Anslinger, & Lasch, 2022).

Common practice is to establish centers of excellence (CoE) when adopting RPA within a company. CoE's benefits over outsourcing are thought to be familiarity with processes, access to confidential information and environment where robots will be implemented (Huang & Vasarhelyi, 2019; Vokoun & Zelenka, 2021).

Also, an important aspect to mention is shaping people's mindset regarding RPA as usually with something new, there is doubt regarding the future and in case of RPA it is quite worrisome that if a robot will start to do your job what will you do then? To address employee's mindset changes, it is common for organizations to do seminars on RPA where RPA's idea, potential and benefits are showcasing through use cases. Invention of RPA ambassadors is also one of the tactics used by companies by assigning this role to specific people inside company who will then work to foster a positive outlook on the emerging technology inside the company. These activities helped in reducing worker's fear regarding job loss by showing them that instead of layoffs RPA will free employees from boring routine work letting them do higher complexity and value tasks (Ågnes, 2021; Marciniak & Stanislawski, 2021).

#### RQ2: How to determine RPA fit process?

A good process to be delegated for RPA according to published articles first of all is rules based – process that follows strict rules and doesn't include judgement or any other human value during process steps and therefore could be automated through if-then decision trees (Hallikainen, Bekkhus, & Pan, 2018; Viale & Zouari, 2020; Kokina & Blanchette, 2021; Kedziora & Penttinen, 2021).

Also, it is mentioned that process should be matured which means it is already polished and won't be a subject to a lot of changes in the future because for RPA every time something changes in process RPA needs re-development that takes time, money, etc (Hedge, Gopalakrishnan, & Wade, 2018; Viale & Zouari, 2020; Vokoun & Zelenka, 2021).

Continuously, it is good to have processes that are routine ones – that happen every then and now and the more often the better. Another benefit for such processes is that their start time can be established while developing and then process can be triggered, for instance, every Monday at noon and executed fully automatically without any human interference (Wewerka, Dax, & Reichert, 2020; Kokina & Blanchette, 2021; Choi, R'bigui, & Cho, 2021).

Extra gains happen when the same process is done frequently or by a lot of people. In this case developers still use resources to develop one process, but its returns are much higher because process can be scaled up to work on multiple machines meaning significant amount of real worker's working hours saved. Another thing to consider is that with frequent and ample processes the amount of idle time of robot is reduced meaning less license and infrastructure money is wasted in downtime. That's why high-volume processes should be considered a priority for automation as they yield the highest potential benefits and return of investment (Hedge, Gopalakrishnan, & Wade, 2018; Wewerka, Dax, & Reichert, 2020; Viale & Zouari, 2020).

Also, processes that interact with multiple systems should be considered a good fit for RPA because when performed manually, with each additional system human interacts the probability of human error increases. While these processes might not bring the most returns in general, in cases of sensitive tasks the RPA dominance in error less performance of tasks can bring significant value and save unexpected time and expenses spent on fixing such human errors (Wewerka, Dax, & Reichert, 2020).

#### RQ3: What are the challenges of RPA adoption?

One of the main challenges is resistance within companies implementing RPA as employees of all levels tend to see RPA as a threat to their jobs. This opinion is mostly based on the lack of awareness of what RPA is about and how its adoption will impact their work in the most general sense (Marciniak & Stanislawski, 2021).

Another issue is that people by nature are cautious of change and are usually happy with the well-known current organization of things. Without clear orders from upper management, they didn't move towards RPA (Viale & Zouari, 2020).

If the company has a lot of paperwork that isn't digitalized, it's a big problem as RPA is good with well digitized processes, as it is hard to extract information from paper, so before RPA this move towards digitalization should be considered as pre-requisite. In broader sense, going from paper to digital isn't just about documents and RPA but change of philosophy in company in general that it is changing its management model moving from traditional to advanced model. And only after this switch can RPA and other advanced digital solutions be implemented with less problems or be implemented at all (Wewerka, Dax, & Reichert, 2020).

#### RQ4: What are the gaps in research?

RPA implementation framework and which processes to give to RPA are questions that seem to be answered in general; research if the same approach can be used by SMEs considering SMEs limited resources and different organizational structure is missing. Also, it would be interesting to see if the same challenges apply to SMEs that were found in literature concerning bigger companies again because SMEs have different employee structure and management.

Research on local SMEs would also be useful to see how well local SMEs adopt RPA, most often how well they don't do that and why, as there should be local nuances if we take into consideration general economical situation in the country, general trends regarding digitization in the country and other local characteristics that may differ from cases found in literature from elsewhere.

#### Conclusions

 After years of little interest, RPA finally got some push in the beginning of 2000's with demand being satisfied by foundation of few main RPA vendors, and in a matter of few years industry was grown enough for published academic research papers to grow significantly.

- 2. Companies who have implemented RPA follow the same 4 to 5 step implementation framework. PoC practice is also common across adopters.
- 3. Process that is fit for RPA is rules-based, matured, has high volume and value, and doesn't require human decision-making capabilities.
- 4. Main challenges are human based workforce fears losing job to robots. To address this issue, it is common practice to work towards employee perception of what RPA is and what their future in the company will be.
- 5. There are gaps in research regarding how RPA appliance works in SMEs and how to make RPA better for SMEs, so this segment adopts this technology faster.

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# EVALUATING EARLY CHANGES IN YOUNG TREE SEEDLINGS UNDER SIMULATED URBAN ENVIRONMENT

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#### Abstract

Urban trees, integral to urban environments, demonstrate intricate responses to atmospheric pollutants like particulate matter (PM), tropospheric ozone ( $O_3$ ), and carbon dioxide ( $CO_2$ ). Notably,  $O_3$  induces oxidative stress in leaf tissues, while PM, consisting of fine airborne particles, interacts with urban trees through foliar deposition. This interaction is particularly interesting as tree canopies are highly effective filters, capturing and accumulating PM on their surfaces.

The present study focused on silver birch, small-leaved lime, and Norway maple seedlings responses to elevated  $O_3$  and  $CO_2$  with and without PM. Maple seedlings exhibited the highest stem height increment, followed by lime and birch. Elevated  $O_3$  and  $CO_2$  without PM led to substantial height increments for lime and maple. Elevated  $O_3$  and  $CO_2$  without PM increased the total polyphenols in lime and maple leaves but decreased the content of total flavonoids in birch and lime leaves.

Our findings underscore the adaptability of lime and maple seedlings to elevated  $O_3$  and  $CO_2$ , positioning them as promising species for urban environments in the face of changing climates. Birch, while exhibiting biochemical changes, demonstrated less pronounced growth responses. This study's insights into the intricate interactions between urban trees and multiple pollutants, particularly the species-specific responses, are of significant value for urban planning and environmental management.

Keywords: urban trees, particulate matter, ozone, CO<sub>2</sub>, seedling height, biochemical effect.

#### Introduction

Urban trees, integral components of the urban environment, exhibit complex responses to atmospheric pollutants such as particulate matter (PM), tropospheric ozone (O<sub>3</sub>) and carbon dioxide (CO<sub>2</sub>). Globally, tropospheric O<sub>3</sub> and PM stand out as the foremost air pollutants affecting plants, as highlighted by numerous studies (EEA, 2019; IPCC, 2019; Yeung et al., 2019; Shahid et al., 2019; Zhao et al., 2020; Oksanen & Kontunen-Soppela, 2021). The O<sub>3</sub> infiltrates leaf tissues, instigating oxidative stress and provoking distinct physiological responses. The PM, encompassing fine particles suspended in the air, interfaces with urban trees through foliar deposition. Tree canopies act as effective filters, capturing and accumulating PM on their surfaces (Currie & Bass, 2008; Mondal & Singh, 2022). Plant stomata, especially those on leaves, absorb or sequester gaseous air pollutants such as CO2 (Nowak & Dwyer, 2007; Nowak et al., 2013; Baraldi et al., 2019). Elevated CO<sub>2</sub> concentrations can induce a stimulation of photosynthesis. Complicating matters, plants in polluted regions face simultaneous exposure to unpredictable combinations of factors, creating multiple stress situations. For example, the PM deposition on leaves disrupted stomatal leaf exchanges, decreasing CO2 assimilation and water exchange (Singh et al., 2020; Singh, 2021).

The aim of the study was to evaluate stem height growth, total polyphenols, and flavonoid content as early indicators of three deciduous tree species: silver birch (*Betula pendula* Roth), small-leaved lime (*Tilia cordata* Mill.), and Norway maple (*Acer platanoides* L.). It investigated the response of these species to artificially induced exposure to elevated  $O_3$  and  $CO_2$  concentrations with and without PM.

#### **Materials and Methods**

One-year-old seedlings of silver birch, small-leaved

lime and Norway maple were grown in pots, the substrate of which contained the optimum nutrition and watering. Seedlings were kept in the open field for a year before the start of the simulation experiment. Selected, visually healthy, two-year-old seedlings were placed in the chambers and treated with (*i*) PM + 180 ppb  $O_3$  + 650 ppm  $CO_2$ , (*ii*) 180 ppb  $O_3$  + 650 ppm  $CO_2$ , (*iii*) PM and (*iv*) control for ten weeks. There were 21 seedlings of each species per treatment.

The height (cm) of seedlings was measured at the beginning of the experiment and ten weeks after the birch, lime, and maple seedlings had grown under simulated conditions in the chambers.

For the analysis of total polyphenols (TPC) and total flavonoid content (TFC), leaf samples were collected in three biological replicates for each tree species from four treatments at the end of the vegetation season. Three composite samples (replicates) were made from each tree species for each treatment. For one composite leaf sample, 4–6 leaves were taken from three seedlings.

Quantifying amounts of TPC and TFC was performed spectrophotometrically using a SpectroStar Nano microplate reader (BMG Labtech, Offenburg, Germany) and 96-well microplates. TPC was determined using the Folin–Ciocalteu reagent according to a modified methodology (Lowry *et al.* 1951). TPC is expressed as micrograms of gallic acid equivalent to one gram of fresh mass (mg/g):

Concentration 
$$(mg/g) = (C \times V)/m$$
 (1),

Here, C is the concentration obtained from the calibration curve (mg/mL), V is the extract volume (ml), and m is the weight of fresh biomass extracted (g).

TFC was estimated by forming a flavonoid-Al (III) complex (Chang *et al.*, 2002). TFC is expressed as micrograms of the quercetin equivalent in one gram of fresh biomass (mg/g):

Concentration  $(mg/g) = (C \times V)/m$ 

Here, C is the concentration obtained from the calibration curve (mg/mL), V is the extract volume (ml), and m is the weight of raw biomass extracted (g).

(2),

For statistical analysis, Lilliefors and Kolmogorov– Smirnov tests checked the normality of the variables. The Kruskal–Wallis analysis of variance (ANOVA) test was used to ascertain the significant differences between the treatments. The means are presented with the standard error of the mean (±SE). Statistical analyses were conducted using the Statistica 12.0 software, and a level of significance of p < 0.05 was chosen in all cases.

#### **Results and Discussion**

In all treatments and the untreated control, the maple, followed by lime and birch seedlings, showed the mean increment in stem height, which was 51-76 cm, 23-27 cm, and 9-11 cm, respectively 'Figure 1'. Elevated  $O_3$  and  $CO_2$  without PM caused a slightly larger height increment for lime and a 1.5 times larger height increment for maple seedlings. PM exposure without elevated  $O_3$  and  $CO_2$  slightly reduced the stem height growth for lime seedlings.



Figure 1. Stem height increment of silver birch, smallleaved lime, and Norway maple seedlings. Experimental treatments include exposure to Particulate Matter (PM), elevated O<sub>3</sub> and CO<sub>2</sub>, and the controls. Different letters show statistical significance of the difference between the treatments at p < 0.05.

The highest TPC in the control seedlings was found in birch leaves (3.1 mg GA g<sup>-1</sup>) and maple (2.8 mg GA g<sup>-1</sup>) 'Figure 2'. The PM treatment and exposure to elevated O<sub>3</sub> and CO<sub>2</sub> did not change the TPC in the lime and maple leaves. The elevated O<sub>3</sub> and CO<sub>2</sub> concentrations without PM caused significantly higher TPC in the leaves of lime (33%) and maple (11%). Compared to the control, the mean TPC of birch leaves was significantly reduced by about 30% when treated with elevated O<sub>3</sub> and CO<sub>2</sub>.



Figure 2. Total polyphenol content (TPC) in leaves of silver birch, small-leaved lime, and Norway maple seedlings. Experimental treatments include exposure to Particulate Matter (PM), elevated  $O_3$  and  $CO_2$ , and the controls. Different letters show statistical significance of the difference between the treatments at p < 0.05.

Among the seedlings of different tree species, the highest TFC ranging between 0.78 and 1.14 mg QA g<sup>-1</sup> of fresh weight was found in birch leaves 'Figure 3'. The PM and elevated  $O_3$  and  $CO_2$  treatment resulted in a significant 31-37% decrease in TFC in birch and lime leaves. Compared with untreated controls, mean TFC decreased by 1.4-1.5 in birch seedlings after exposure to elevated  $O_3$  and  $CO_2$ , irrespective of PM treatment. The mean TFC slightly decreased in lime seedlings after exposure to elevated  $O_3$  and  $CO_2$  with PM treatment.



Figure 3. Total flavonoid content (TFC) in leaves of silver birch, small-leaved lime, and Norway maple seedlings. Experimental treatments include exposure to Particulate Matter (PM), elevated O<sub>3</sub> and CO<sub>2</sub>, and the controls. Different letters show statistical significance of

the difference between the treatments at p < 0.05. Elevated CO<sub>2</sub> enhances plant growth by improving photosynthetic carbon assimilation, though prolonged exposure may lead to photosynthetic down-regulation, especially under nutrient-limiting conditions. Previous studies noted that elevated CO<sub>2</sub> concentrations cause more intensive plant growth followed by higher productivity (Ainsworth & Long, 2005), while  $O_3$ causes phytotoxic effects on vegetation (Agathokleous *et al.*, 2018). The CO<sub>2</sub> and O<sub>3</sub> could negatively affect plant growth (Ashmore, 2005; Karnosky *et al.*, 2005; Wittig *et al.*, 2009).

Summarising, lime seedlings exhibited notable increases in height when subjected to elevated levels of O<sub>3</sub> and CO<sub>2</sub>, demonstrating a significant degree of tolerance in terms of biochemical parameters. This adaptability and growth responses make this species well-suited for urban environments. Maple seedlings also experienced heightened growth under elevated  $O_3$ and CO<sub>2</sub> conditions, showcasing adaptability despite variations in specific biochemical responses. The overall growth performance suggests that maple could be a valuable species for urban landscapes. In environments with elevated CO<sub>2</sub> levels due to changing climates, lime displayed increased height increments and exhibited biochemical resilience under elevated O<sub>3</sub> and CO<sub>2</sub> conditions. Similarly, maple demonstrated height increments under elevated O<sub>3</sub> and  $CO_2$ . These two species emerge as promising candidates for growing in urban territories under higher  $CO_2$  concentrations.

#### Conclusions

- 1. The short-term effect did not thoroughly evaluate how urban tree seedlings would respond to stressful conditions caused by increased PM,  $O_3$  and  $CO_2$  concentrations.
- 2. Norway maple seedlings, which increased in height under elevated  $O_3$  and  $CO_2$  despite varying biochemical responses, showed potential for adaptation to simulated urban environmental conditions. Among the studied species, small-leaved lime seedlings appeared to have a higher biochemical resistance to simulated conditions than silver birch and could be more adaptable to urban environments.

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# MACHINE LEARNING BASED CLASSIFICATION OF PEAT LAYER THICKNESS IN LATVIA USING NATIONAL FOREST INVENTORY DATA

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#### Abstract

This study investigates the distribution and carbon content of organic soils in Latvia, leveraging machine learning techniques alongside remote sensing and National Forest Inventory (NFI) data to enhance the precision of organic soil mapping. Our approach integrates data from various sources, including airborne laser scanning (ALS) data, digital elevation models (DEM), depth-to-water (DTW) and wet area maps (WAM), and historical organic soil data. By classifying over 24,000 soil probing measurements across Latvia into distinct peat layer thickness categories, we develop a machine learning model that categorizes the thickness of the organic layer with notable accuracy. Our findings indicate that the model, particularly when employing the xgbTREE algorithm and over-sampling method, successfully identifies areas with peat layers thicker than 40 cm, demonstrating a significant improvement over traditional mapping methods. The study reveals an underestimation of organic soil coverage in Latvia by previous estimates, suggesting a broader distribution than recognized, with the model achieving an accuracy of 0.86 and a kappa value of 0.67. This research not only underscores the efficacy of integrating machine learning and remote sensing for soil mapping but also highlights the critical role of accurate data and models in determining organic soil distribution. The insights gained from this study are vital for policy-making and environmental planning, offering a more detailed understanding of Latvia's peatland resources and their conservation needs.

Key words: LiDAR, organic soils, topography.

#### Introduction

Peatlands provide essential services such as storing carbon, producing biomass, and regulating climate. However, they are being degraded by climate change and swift changes in land use, releasing their carbon (C) reserves (Joosten *et al.*, 2016; Minasny *et al.*, 2019). Understanding their size, condition, and carbon stocks is crucial for their conservation and to support the goals of the Paris Agreement. Despite covering just about 2.8% of the global land area, peatlands play a critical role in carbon storage, holding between 33% to 50% of the world's soil carbon reserves (Hilbert, Roulet, & Moore, 2000; Frolking *et al.*, 2011; Li *et al.*, 2018).

Organic soils are defined by their buildup of organic material based on their organic content, degree of decomposition, and water saturation levels. Within histosols, further distinctions are made, such as fibric, which consists of less decomposed peat; hemic, with partially decomposed organic material; and sapric, representing highly decomposed peat. These classifications help in understanding the characteristics and ecological functions of organic soils across different environments.

The landscape's topography and the bedrock beneath play a crucial role in creating moist conditions. The shape of the land affects water runoff, the connectivity of water networks, and the pooling of water, as noted by Jencso *et al.* (2009). The climate has a significant effect on the moisture content of the soil, with rainfall influencing the levels of groundwater, surface runoff, reduction reactions, and the buildup of organic materials. The temperature influences the activities of microorganisms and plants, which in turn affects the accumulation and breakdown of organic materials (Deluca & Boisvenue, 2012). It is also a factor in the rate of evaporation and the overall moisture regime of wetlands. In the boreal forests, the commonality of

moist soil is attributed to elevated groundwater levels. These moist conditions, along with lower temperatures, retard the decomposition of organic materials, favoring the formation of peat (Luke et al., 2007). Peat, with its superior capacity to retain water compared to mineral soils, enhances moisture retention in specific locales (Åström, Aaltonen, & Koivusaari, 2001). Wet soils are not merely repositories of moisture but also hubs for organic material. Observations indicate that areas prone to runoff and associated with wet soils exhibit similar concentrations of organic carbon compounds. This freshly derived organic carbon highlights the interplay between watercourses and soil. The transference of organic matter from moist soils mirrors in the flux of elements such as organic nitrogen, phosphorus, and sulfur, similar to the release of organic carbon (Ledesma et al., 2018).

Digital Elevation Models (DEMs) are instrumental in examining natural processes related to the landscape, and thematic maps provide further insights into their effects across different regions. Depth-to-Water (DTW) maps offer a model of groundwater proximity to surface water features like rivers and lakes (Lidberg, Nilsson, & Ågren, 2020), whereas maps of soil wetness reflect the influence of the underlying bedrock (Ivanovs & Lupikis, 2018). This study aims to identify the distribution of organic soils and its carbon content by comparing historical soil maps with predictions using remote sensing data.

#### Materials and Methods

The research area covers the entire territory of Latvia. According to historical soil maps, mire distribution data, forest growth condition data, peat extraction license data and other data sources, organic soils in Latvia cover an area of 6958 million square kilometers or 10.78% of land area 'Figure 1'. This estimation is based on the data on the organic soil coverage derived from the results of the Paliduculture in the Baltics project (Piirimäe *et al.*, 2020).



Figure 1. Distribution of organic soils in Latvia.

Data were collected from NFI sample plots located in forested areas, where the depth of the peat layer was assessed through soil probing. In each plot, this probing was conducted four times in each cardinal direction (North, East, South, and West), 12.5 meters away from the plot's center, resulting in a total of over 24,000 measurements. Subsequently, these measurements were categorized into three classes that represent four peat layer thickness ranges: plots with either no peat layer or one up to 5 cm thick, plots with peat layers up to 20 cm thick, plots where the peat layer's thickness is between 20 and 40 cm, and plots with peat layer thickness exceeding 40 cm.

The training dataset comprises a variety of variables sourced from ALS (Airborne Laser Scanning) data and additional cartographic materials, all at a 5 m horizontal resolution. The variables incorporated into the machine learning model include:

- DEM (Digital Elevation Model): A terrain model derived from ALS data, provided by the Latvian Geospatial Information Agency.
- Historical Organic Soil Data: A data layer generated by amalgamating historical soil maps, mire distribution data, data on forest growth conditions, peat extraction license information, and other data sources.
- DTW (Depth to Water): Maps indicating water depth with catchment areas of 10 and 30 hectares, created earlier in the research using ALS data.
- WAM (Wet Area Maps): Maps identifying wet areas, also prepared in prior research stages from ALS data.
- Normalized Height Maps: Models normalizing the Earth's surface relief.
- Slope: Models depicting the slope of the Earth's surface.
- Saga Wetness Index: A moisture index based on a modified calculation of the catchment area, as discussed by Böhner & Selige (2006).
- Soil Data: Data concerning soil texture.

- Proximity to Water: The distance to the nearest body of water, such as a river, lake, or sea.
- Continentality: The distance from the sea.

X and Y Coordinates: Geographical positioning data. The categorization of the organic layer's thickness was executed using the 'Caret' package in R. The NFI dataset, divided into three categories of peat thickness, was randomly split into 80% for training and 20% for testing. Various machine learning classification algorithms, including *xgbDART*, *xgbTREE*, among others, were evaluated. To mitigate the influence of an imbalanced dataset, different strategies were exploredover-sampling, under-sampling, and the SMOTE algorithm. All models underwent parameterization and optimization through a grid-search methodology coupled with 5-fold cross-validation to identify the optimal model. These fine-tuned models were then applied to the test data and assessed using Cohen's kappa index to measure agreement.

#### **Results and Discussion**

The machine learning model employing the *xgbTREE* algorithm, in conjunction with the over-sampling method, yielded the best classification outcomes and the highest kappa value. 'Figure 2' illustrates the influence of different remote sensing data and cartographic materials on the classification results. The most critical parameter was found to be continentality, followed by the depth-to-water index and DEM (Digital Elevation Model) values.



Figure 2. Feature importance in the model.

The accuracy of the overall machine learning classification algorithm reaches 0.86, while the kappa value is 0.67. Separately, by different classes, sensitivity reaches:

Soils without peat layer or up to 5 cm - 0.96;

Soils with a layer of peat from 5 to 20 cm - 0.45; Soils with a layer of peat thickness 20-40 cm - 0.39; Soils with a peat layer > 40 cm - 0.8.

'Figure 3' presents the classification outcomes for Latvia's landscape.



Figure 3. Map of modelled peat layer thickness in Latvia.

The data reveal that areas with a peat layer thickness ranging from 5 to 20 cm account for 0.7 % (461 km<sup>2</sup>) of Latvia's land, while 1.7% (1120 km<sup>2</sup>) of the country is overlain by peat layers between 20 and 40 cm thick. Additionally, a substantial 16.8% (10858 km<sup>2</sup>) is characterized by peat layers exceeding 40 cm in thickness. These findings mark a deviation from the previously estimated coverage of organic soils in Latvia, which stood at 10.8%. This discrepancy is likely due to variations in the precision of organic soil mapping and the spatial resolution of the areas analysed. An evaluation of the existing organic soil distribution maps against the newly acquired NFI plot data reveals an accuracy rate of 0.76 and a kappa statistic of 0.39. This comparison underlines the significant enhancement in accuracy and insight into the distribution of organic soils across Latvia facilitated by the applied machine learning algorithm. Peatland mapping techniques vary according to peatland accessibility and the resources at hand. In the EU, nations such as Finland and Sweden utilize their robust data infrastructures to generate accurate peat maps via country-wide gamma radiometric surveys, which allow for the distinction between shallow and deep peat layers (Lilja & Nevalainen, 2006, Väänänen et al., 2007).

Canada has successfully utilized remote sensing and DSM for extensive territory mapping. Recently, employing a variety of remote sensing methods has proven exceptionally effective for generating high-resolution outcomes in targeted, regional research efforts. For example, Hird *et al.* (2017) achieved the mapping of Alberta's peatlands by combining

multispectral satellite data, digital elevation models (DEM), and synthetic aperture radar (SAR) imagery, with additional data from forest inventory plots. In a similar manner, Bourgeau-Chavez et al. (2017) utilized a technique for their research in regions rich in permafrost. Additionally, the application of airborne LiDAR has been acknowledged for its precision in mapping peatlands at a high level of detail, as demonstrated by research conducted by Millard & Richardson (2013) and Chasmer et al. (2016), even though its use is somewhat restricted. While Indonesia has tested digital soil mapping, it has not yet been implemented nationwide. To support effective spatial planning and policy formulation, it is necessary to have a peat map of at least 1:50,000 resolution or a spatial accuracy of 30 meters or better. Various research efforts have distinguished peatlands using satellite imagery (including visible and infrared wavelengths) (Wijedasa et al., 2012), as well as radar data (Novresiandi & Nagasawa, 2017). Some researchers have attempted to determine peat depth using only elevation data (Jaenicke et al., 2008). However, only a handful of studies have employed digital mapping methods to assess peat thickness. The peatlands in these regions are typically dispersed and difficult to access, suggesting that mapping strategies should combine remote sensing technology with direct field observations.

Accurately determining peat layer thickness at a granular scale presents challenges due to the complex and often unknown nature of the underlying mineral terrain (Kettridge *et al.*, 2008). However, identifying regions where landforms suggest sustained high

moisture levels enables the identification of zones with significant long-term peat accumulation, leading to denser peat layers (Comas, Slater, & Reeve, 2004). Our study included several LiDAR derived soil moisture indicators, like WAM and DTW maps, to train our machine learning model. These indicators are crucial in the feature importance hierarchy of the machine learning model's development (Lidberg, Nillson, & Ägren, 2020, Deluca & Boisvenue, 2012). It should be noted that the quality of the DEM has a significant impact on the accuracy of the used models, how well it is prepared for hydrological modelling. For example, from whether correct input data for existing roads, ditches, culverts, which correspond to DEM have been available, to make its corrections in these places.

#### Conclusions

- 1. Our model using machine learning techniques, remote sensing and NFI data provides high accuracy of peat layers with different thicknesses spatial distribution, comparing to other available data sources.
- 2. Most important model input data variables was continentality, depth to water map and DEM. However, it should be noted that the accuracy of

our model is affected by the accuracy of input data and models, such as depth to water and wet area map and other terrain indices.

- 3. The results reveal that best model performance is obtained for identifying peat which is thicker than 40 cm.
- 4. More research is needed which may improve the model performance regarding different peat thicknesses as well as considering usage of different satellite data products for training the model.
- 5. Our study provides more insight into organic soil distribution in Latvia, comparing to older data sources which can be taken into account by GHG inventory teams and policy makers.

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# THE EUROPE UNION GREEN DEAL AS A FACTOR FOR CHANGES IN BUSINESS: THE EDUCATIONAL PERSPECTIVE

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#### Abstract

Sustainability, green growth and the European Union Green Deal principles are the cornerstones that should and will affect our lives. The aim of the paper is to provide possible improvements to higher education programmes to promote the implementation of the EU Green Deal as a factor for changes in business. The research is based on investigations into the entrepreneurship students' knowledge of the EU Green Deal. A theoretical analysis of literature and policy documents were investigated to develop an appropriate questionnaire for the survey of Latvian university students. The research methods involve measures of central tendency and location, T-test, ANOVA and correlation analysis. The research results indicate that business curricula involve courses on Sustainable Development and universities' role in teaching the Green Deal because the students who hold experience in entrepreneurship report similar results if compared with students without experience in entrepreneurship. Students' knowledge of the EU Green Deal should be improved since there are a number of aspects where the answers were not correct. This, in turn, prompts the need to strengthen and diversify education, so that business transformation towards the Green Deal is successful. The curricula should be further improved, as it allows students to better understand EU and global trends in saving the planet and put the knowledge into practice in their companies.

Keywords: education, entrepreneurs, EU Green Deal, higher education students, knowledge, sustainability.

#### Introduction

As part of the Green Deal (GD), the European Union Member States must implement various programmes and instruments that achieve the goal of ensuring net emissions of greenhouse gases by 2050. The Member States should not only reduce greenhouse gas emissions from agriculture but also increase carbon sequestration, increase the sustainability of agricultural production, improve biodiversity in rural areas and help to provide the population with nutritious and healthy food, including by promoting the development of the bioeconomy.

From the perspective of the European Commission, education plays a central role in global political efforts to promote sustainability and combat climate change. In its 2020 Communication 'On Achieving the European Education Area by 2025', the European Commission states that education and training policies and investments aimed at an inclusive green and digital transition are recognized as essential for Europe's future resilience and prosperity. This aspect points to the urgency of improving curricula that incorporate the theme of the GD and train young people as potential green converters in the practical implementation of its principles.

The author (Zotti, 2022) emphasizes that the strategic goal of the EU education reform is much broader than small adjustments to existing curricula, that is, it places sustainability at the centre of the European education policy reform programme. This means (Zotti, 2022) that better education and training should support not only environmental sustainability but also a general concept of sustainability, which also drives the politicians' agenda for better, more qualitative and inclusive education in Europe.

A holistic approach to the implementation of bioeconomy strategies for improving business economic performance involves several factors, including knowledge generation and dissemination. The importance of transformative business activity is recognized in the bioeconomy strategies of many countries around the world (Kuckertz, 2020). This shows the need to improve business education at all levels – professional, higher education and research.

Some research studies demonstrate (e.g. Lamenta & Grzybowska, 2023) that for entrepreneurs from several European countries, the awareness of the GD goals is still a challenge for achieving these goals in practice. Consequently, the role of awareness and especially formal education in the creation and implementation of the green economy in business in the future is increasing. The results of a research study (Krajnc et al., 2022), which surveyed young people in five EU countries, showed a lack of knowledge about the GD priorities and circular economy principles and their connection to business activities in most areas. Moreover, formal education did not provide enough knowledge for young people to successfully operate in the green transformation of business (Krajnc et al., 2022). Another research study (Tooman & Piirman, 2019) on micro-enterprises in Estonia, Finland, Latvia and Sweden determined the skills and knowledge most needed for green entrepreneurship and business development. The research revealed that although micro-entrepreneurs had enough natural business ideas, they lacked the skills to turn them into a profitable green business and the supply of products and services. For many entrepreneurs, it is important to get practical skills, as they need to know 'how to do' rather than 'what to do'.

In Latvia, some researchers have focused on researching the linkage of the content of tertiary education programmes with the topics of the GD framework. Thus, the authors (Kalnbalkite, Pubule, & Blumberga, 2022), examining the master's programme 'Environmental Engineering' established at the Institute of Energy Systems and Environment of Riga Technical University, the field of study 'Bioeconomics', emphasize the complex nature of the training. This research study highlights the critical role of higher education in achieving the goals of the GD and the bioeconomy, including competence-based learning.

Education adapted to the Green Deal not only contributes to the country's green transformation and sustainability but also plays a crucial role in preventing the economic consequences of climate change, especially in terms of its impact on the labour market and adapting the necessary skills and competencies to the future workforce (Zotti, 2022).

Thus, it is important to find out whether Latvian university students have an understanding of the GD and whether the programmes offered contain sufficient green knowledge for business transformation.

The aim of the research is to provide possible improvements to higher education programmes to promote students' knowledge of the GD. An understanding of this topic enhances the ability of budding entrepreneurs to implement green change. Therefore, improved education is one of the change factors for implementing the GD principles in business.

### **Materials and Methods**

The task set forth in the research is to identify the level of knowledge of the students in universities as potential implementers of the green transformation of the national economy in the areas of the GD. For this task, a survey was conducted among the students, so that the data obtained could be used for in-depth research.

The research was initiated in several steps, see 'Figure 1'.

In order to conduct the survey, literature sources and the EU and Latvian strategies and policy documents related to the topic of the GD were reviewed. The survey questions were formulated using several sources, the main of which was the GD strategy adopted by the European Commission in 2019, as well as the Latvian Common Agricultural Policy Strategic Plan 2023-2027. This Latvian strategy, in turn, includes EU 2030 goals and measures set in the EU strategy 'Farm-to-Fork' and the EU Biodiversity Strategy 2030.

The survey questionnaire was distributed anonymously

among students of master's and doctoral programmes in paper and electronic format at four Latvian universities: Latvia University of Life Sciences and Technologies, Liepaja University, Turiba University and the University of Latvia. The programmes of the selected universities include courses that cover the topics of the GD and the economy.

The survey was conducted from 07/12/2023 to 15/02/2024. A total of 179 responses were received, of which four were deemed inappropriate.



Figure 1. Scheme of conducting the research.

#### **Results and Discussion**

The SPSS software platform was used for statistical analysis. There were students with and without experience in entrepreneurship who participated in the survey. Taking into account that students who worked might have attended some seminars on green growth, the two groups were compared. Yet, at the same time, following the data that the average experience for students in business was 1-2 years, the  $H_0$  was set that the means of the two groups were equal. Alternatively, the  $H_1$  was set – the difference between the groups was significant (see Table 1 and Table 2).

Table 1

Group Statistics							
	Yes – 1; No - 2	Ν	Mean	Std. Deviation	Std. Error Mean		
How important is the implementation of	1	72	0.10	0.298	0.035		
the Green Deal in Latvia?	2	103	0.05	0.216	0.021		

Taking into account the test results, we failed to reject the null hypothesis. We did not have sufficient evidence to say that the true mean was different between students holding experience in entrepreneurship and students without experience in the field.

Table 2

Independent Samples T-Test										
Levene's t for equality variance			ne's test uality of ances	t-test for equality of means						
		F	Sig.	t	df	Sig. (2- tailed)	Mean Difference	Std. Error Difference	95% c interv diff	onfidence val of the ference
	Equal								Lower	Opper
Experience in entrepreneurship	variances assumed	6.355	0.013	1.252	173	0.212	0.049	0.039	-0.028	0.125
	Equal variances not assumed			1.184	121.219	0.239	0.049	0.041	-0.033	0.130

The main purpose of the questionnaire was to find out the students' awareness of what the overarching goal of the GD was. The results showed that, in general, the students knew the GD (see 'Table 3'). The answers showed that most of the respondents (72%) had an idea of the main goal of the GD – for Europe to become a climate-neutral part of the world and to achieve zero greenhouse gas (GHG) emissions by 2050. The majority (60%) were aware that the Green Deal also has an intermediate target of reducing GHGs by at least 55% by 2030 compared with 1990 levels. It is noteworthy that 70% of students with experience in business management and 55% without such experience were aware of this specific target, which resulted in the EU regulatory package 'Fit for 55' in 2021.

Table 3
Student responses regarding the main objective of
the European Union's Green Deal

the European Union's Green Dear							
Answer	Percent of all						
Achieve climate neutrality in the EU by 2050	72						
Reduce GHG emissions by at least 55% compared with 1990 levels in the EU by 2030.	60						
Restrict global warming and ensure that GHG emissions are significantly reduced	58						
Other	3						

The GD has been introduced to reorient the EU's economic development in line with the United Nations' 2030 Agenda and Sustainable Development Goals. With this in mind, the survey included a question about the sustainable development strategies of the GD. The responses showed that majority of the students were aware of the most important strategies of the GD framework, see 'Figure 2'. The GD integrates several strategies and develops diverse policies, in particular on biodiversity, the circular

economy, climate change, food systems, forest protection and restoration, and renewable energy. The answers reflected the areas about which the students were most likely to have acquired knowledge. The fact that the majority pointed to a strategy related to energy and the use of renewable energy resources is reasonable. The EU Climate Action Plan and subsequent regulatory documents on renewable energy were introduced earlier than the GD initiative. The aspect of energy efficiency is included in several Latvian policy documents, starting with the Sustainable Development Strategy of Latvia until 2030, adopted in 2010. It is no surprise that universities have developed curricula in this field.

In Latvia, the directions to the Green Deal are included in several strategies important for the development of the national economy, and the need for educated human resources is emphasized in them. For example, the Latvian Bioeconomy Strategy 2030 (adopted on 19/12/2017) envisages the provision of excellent educational services for the needs of bioeconomy industries. The strategy states that high-quality knowledge that meets the demand of the bioeconomy sectors can be developed at three levels - professional, higher education and lifelong learning. It was emphasized that excellence should be achieved in higher education by supplementing the acquired in the specific knowledge speciality with entrepreneurial skills and knowledge. The Latvian Common Agricultural Policy Strategic Plan 2023-2027 (adopted on 18/01/2022) is an important instrument aimed at measures and investments to achieve the goals of the GD, including reducing GHG emissions, reducing the use of plant protection products and fertilizers and increasing the area of organic agriculture. This plan particularly emphasizes the need for quality education and knowledge, and therefore access to education, upskilling and retraining should be promoted. Unfortunately, the need to include knowledge about the Green Deal, its goals and strategies and to acquire relevant skills in the implementation of the Green Deal in the national economy in the Latvian Education Development Guidelines 2021-2027, which were adopted in 2021, has not been emphasized in training at universities. These examples show that the education development strategy is not aligned with the implementation of strategies vital to Latvia's economy. In practice, the content of courses and their improvement are actually the responsibility of the management and scientific staff of each higher education institution.



Have or had experience in business management
 No experience in business management

Figure 2. Student responses on sustainable development strategies within the framework of the European Union's Green Deal (n=175).

The research goals of EU researchers in the field of education go beyond simply improving the level of awareness of learners. To promote learning about environmental sustainability in the EU and the GD, the European Sustainability Competence Framework was developed in 2022. It aims to provide guidelines for the development of sustainability competencies to be incorporated into educational programmes across the EU. According to this Framework, the green transformation requires not only specific knowledge and skills but also 12 sustainability competencies, which the authors have divided into four clusters: 'embodying sustainability values', 'embracing complexity in sustainability', 'envisioning sustainable futures' and 'acting for sustainability' (Zotti, 2022). Not all the students were sufficiently clear about the values of sustainability and had a vision of implementing the GD for the sustainable development of the national economy. To assess the students' perceptions of how important the implementation of the EU Green Deal in Latvia was, a scale from one to five was used, where one means 'not important' and five means 'very important'. Comparing the answers of the group of students with experience in business management and those without such experience, it could be seen that the distribution of answers differed little. Ten percent of students with business management experience and 7% without it considered the implementation of the Green Deal as generally unimportant or less important. However, the majority of

respondents believed that the green transition was generally important for Latvia - 75% of both groups indicated it. In response to the question how important was the implementation of the EU Green Deal in Latvia, one of the answers was: '...currently research is of great importance because it is necessary to take into account the factors in global climate and environmental changes that can affect the development of the business environment in the coming periods. Researchers need to work more closely with representatives of practical business and policymakers to promote the development of a sustainable business environment'. However, another respondent had a worrying belief: 'When talking to politicians in Latvia, sustainability is not mentioned as a priority'. Another important answer was: 'If a person him/herself does not think or does not want to think about not destroying his/her home (the Earth), then this Green Deal will force him/her to do it'. The responses showed a diversity of opinions, which was likely based on differences in awareness of the GD and the positions or activities of its policymakers. An analysis of variance (ANOVA) showed whether there were statistically significant differences between groups of respondents in their separate answers to two questions: 'Which of the sustainable strategies are part of the Green Deal?' and 'In your opinion, how important is the introduction of the EU Green Deal?' (Table 4). The data showed that there were only two questions where significant differences could be found in terms of opinions about sustainable strategies as part of the GD.

The students were asked to indicate the strategies that formed a part of the GD. Although it was possible to click all the answer options, it happened in no cases. This fact leads to an indication that the students needed a deeper understanding of the GD.

A correlation analysis was performed to investigate

relationships among the answers indicated (Table 5). There were a number of significant correlations, yet the numbers were expected to be higher. Moreover, it should be considered that there was a negative (although not significant) correlation between the indicators 'Energy efficiency' and 'Sustainability of the urban environment'.

Table 4

Main statistical indicators for testing a statistical hypothesis with analysis of variance (ANOVA) for the
difference between the sustainable strategies as a part of the EU Green Deal and the opinions on the
introduction of the EU Green Deal in Latvia

Analysed aspect	Indicator	Sum of Squares	df	Mean Square	F	Sig.
	Between groups	0.001	1	0.001	0.109	0.742
Energy efficiency	Within groups	1.976	172	0.011		
	Total	1.977	173			
	Between groups	0.124	1	0.124	0.961	0.328
Circular economy	Within groups	22.780	176	0.129		
	Total	22.904	177			
	Between groups	1.486	1	1.486	6.293	0.013
Biological diversity	Within groups	41.575	176	0.236		
	Total	43.062	177			
Constain a hiliter of the	Between groups	0.581	1	0.581	2.499	0.116
Sustainability of the	Within groups	40.947	176	0.233		
	Total	41.528	177			
Sustainability of	Between groups	0.191	1	0.191	0.763	0.383
agricultural and food	Within groups	43.950	176	0.250		
systems	Total	44.140	177			
	Between groups	0.699	1	0.699	2.814	0.095
Organic farming	Within groups	43.750	176	0.249		
	Total	44.449	177			
Digitization and	Between groups	0.089	1	0.089	0.354	0.553
innovation	Within groups	44.411	176	0.252		
	Total	44.500	177			
	Between groups	1.343	1	1.343	5.599	0.019
Other strategy	Within groups	42.208	176	0.240		
2.	Total	43.551	177			

Table 5

# Main statistical indicators of correlations between responses on the sustainable strategy under the Green Deal

Analysed	Statistical	Energy	Circular	Biological	Sustainability of the urban	Sustainability of agricultural	Organic	Digitization and	Other
aspect	mulcators	efficiency	economy	urversity	environment	systems	ranning	innovation	suategy
Energy	Pearson Correlation	1	-0.113	0.088	-0.030	0.009	0.003	-0.002	-0.018
efficiency	Sig. (2- tailed)		0.135	0.248	0.694	0.903	0.968	0.981	0.812
	N	175	175	175	175	175	175	175	175
Circular economy	Pearson Correlation	-0.113	1	-0.032	0.222**	0.164*	0.030	0.143	0.112
	Sig. (2- tailed)	0.135		0.670	0.003	0.029	0.687	0.056	0.137
	N	175	179	179	179	179	179	179	179
Biological diversity	Pearson Correlation	0.088	-0.032	1	0.157*	0.046	0.366**	0.175*	0.161*
	Sig. (2- tailed)	0.248	0.670		0.036	0.537	0.000	0.019	0.031
	N	175	179	179	179	179	179	179	179

							Continua	tion of th	e Table 5
Sustainability of	Pearson Correlation	-0.030	0.222**	0.157*	1	0.239**	0.374**	0.339**	0.130
the urban	Sig. (2-tailed)	0.694	0.003	0.036		0.001	0.000	0.000	0.084
environment	N	175	179	179	179	179	179	179	179
Sustainability of	Pearson Correlation	0.009	$0.164^{*}$	0.046	0.239**	1	0.294**	0.298**	0.281**
agricultural and	Sig. (2-tailed)	0.903	0.029	0.537	0.001		0.000	0.000	0.000
food systems	Ν	175	179	179	179	179	179	179	179
	Pearson Correlation	0.003	0.030	0.366**	0.374**	0.294**	1	0.464**	0.283**
Organic farming	Sig. (2-tailed)	0.968	0.687	0.000	0.000	0.000		0.000	0.000
	Ν	175	179	179	179	179	179	179	179
Digitization and	Pearson Correlation	-0.002	0.143	$0.175^{*}$	0.339**	0.298**	0.464**	1	0.163*
innovation	Sig. (2-tailed)	0.981	0.056	0.019	0.000	0.000	0.000		0.029
mnovation	Ν	175	179	179	179	179	179	179	179
	Pearson Correlation	-0.018	0.112	0.161*	0.130	0.281**	0.283**	0.163*	1
Other strategy	Sig. (2-tailed)	0.812	0.137	0.031	0.084	0.000	0.000	0.029	
	Ν	175	179	179	179	179	179	179	179
** Correlation is significant at the 0.01 level (2-tailed).									
* Correlation is sig	* Correlation is significant at the 0.05 level (2-tailed).								

The international research study (Krajnc *et al.*, 2022) has identified a lack of knowledge among young students about the circular economy to achieve the goals set by the GD. The researchers draw attention to the fact that, despite young people's support for the circular economy concept, they were not sufficiently trained to create new solutions for the implementation of the circular economy. The authors of this research study recommend introducing systemic measures in the field of education to more intensively involve young people in the implementation of the GD and the circular economy. Some of them are also suitable for improving the Latvian education system, including:

- creation of awareness of the circular economy, the GD and sustainability in business at all levels of education;
- creation of interdisciplinary, responsive environmental education curricula that meet the goals of sustainable development;
- development of diverse skills, providing opportunities for the use of knowledge in practice;
- use of forums in education for cooperation with young people, where they can be more motivated to ensure circular economy principles (Krajnc *et al.*, 2022).

An interdisciplinary approach in the bioeconomy entrepreneurial ecosystem is supported by researchers (Kuckertz, Berger, & Brändle, 2020) who emphasize the alliance between bioeconomy start-ups and universities. Regarding the improvement of education in the field of the bioeconomy, the researchers recommend that universities focus on increasing the individual motivation of students and providing educational activities that strengthen the entrepreneurial behaviour of students and faculty (Borge & Bröring, 2020).

Some research studies reveal that the lack of business support services is a major obstacle to the growth and competitiveness of SMEs. For example, a research study (Daoudi *et al.*, 2023) emphasizes that SMEs need coordinated support to implement green and circular economy innovations. Critical support services include, but are not limited to, business management capacitybuilding services based on successful business experience. Services would help SMEs to acquire the knowledge and skills to better manage their businesses and adopt circular and green economy practices. The authors recommend that such services should combine advanced training programmes with mentoring and consulting services on various aspects of strategic management. In order to create future-ready entrepreneurs and workforces, curricula should be designed to develop entrepreneurial skills, including topics in strategic business planning, financial analysis and supply chain management.

A limitation of this research study was that the survey was restricted to students from some bachelor, master and doctoral programmes that have varying levels of knowledge, perceptions and experience. Therefore, the results of the research only shed light on the problems in education, which aim to provide knowledge about the areas of the GD.

Most likely, only professionals equipped with relevant knowledge, skills and competencies will be able to make a green transition in the national economy.

#### Conclusions

- 1. The majority of the surveyed higher education students cared about a climate-neutral and sustainable future and had general knowledge about the GD and sustainability. However, this knowledge did not indicate a complete readiness to accomplish a green transformation in business, and thus to implement the principles of the GD in the national economy.
- 2. There is an urgent need to develop a special curriculum adapted to each university, for example, 'Ecology and environmental protection', including a special section on the GD, green thinking, and the possible impact of climate change on the environment and society. The urgency of improving the programmes stems from the need in the coming

years – to achieve the goals of climate neutrality in 2050 and 55% reduction in GHG emissions in 2030.

3. Higher education institutions should consider that education programs should be created using an interdisciplinary approach, emphasizing the acquisition of skills for the practical implementation of GD principles for the development of future professionals' knowledge and sustainability competencies.

4. Awareness of sustainability values, supplemented with specific knowledge and special skills, is a priority that should be further developed in educational programmes in the field of Green Deal. It is also essential to focus on business management capacity-building skills to bring the green transformation to life.

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# THE IMPACT OF COVID-19 ON THE EMOTIONAL AND PSYCHOLOGICAL WELL-BEING OF STUDENTS

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#### Abstract

Students experienced various challenges during the COVID-19 pandemic, e.g., distance learning, which caused limited faceto-face socialization opportunities with peers, leading to loneliness and anxiety. Loneliness and anxiety are known to be associated with psychological difficulties such as depression or lack of motivation, feelings of anxiety and difficulty concentrating on work, etc. COVID-19 also had an impact on the physical health of young people, such as back pain when sitting at the computer, eye pain and other difficulties. Although COVID-19 is no longer an issue, young people studying remotely during the pandemic are now our learners. Therefore, the aim of this study is to identify the emotional state of school youth at the moment and the impact of COVID-19 on their mental health, as researches show that three-quarters of all mental disorders appear before the age of 24. At this age, there are rapid changes in the body as well as the formation of personal identity. Based on these considerations, the Nordplus project 'Methods for working with young people to ensure learning process resilience' was initiated, in which surveys of students and teachers were organized, and six different educational institutions from three Baltic states participated in the study. Results show that students feel tired, anxious, and angry and have too heavy workload. Teachers think that physical activity, sports and help with studies could reduce the mental health problems of students, but for students, it is most important to spend more time with friends.

Keywords: Covid-19, emotional state, mental health, pandemic, psychological well-being.

#### Introduction

The Covid-19 pandemic has significantly affected all areas of young people's lives - education, employment and leisure, as well as mental well-being. At the beginning of 2021, the Adolescent and Youth Psychotherapy Center published the study 'The impact of the restrictions of the Covid-19 pandemic on Latvian adolescents and young people'. According to the research data, 54.5% of young people admitted that their mental health had deteriorated during the Covid-19 pandemic, 70.4% admitted that they had experienced depression, 79.2% encountered difficulties in learning, and more than 60% experienced intrusive thoughts or were very easily irritated. A fifth of the respondents admitted that they faced psycho-emotional challenges at school. As one of the mental health problems, 43.2% of young people indicated excessive use of the computer and social networks. The research data show that the biggest problems for young people were studies (64%), spending free time (48%) and lack of physical activities.

In the first wave, young people mostly rated their mental health as good (38.1%) or acceptable (24.3%), while in the second wave, 'acceptable' (31.6%) and 'bad' (29.8%) already prevailed. The number of young people who feel very good during the pandemic decreased sharply (from 19.5% in the 1st wave to 7.6% in the 2nd wave), but the number of those who feel critical and destructive is increasing (from 4.6% in the 1st wave to 7.8% in the 2nd wave).

Similar data have also been obtained in other studies. Students experienced various challenges during the pandemic and distance learning (e.g., Tannert & Gröschner, 2021). The students had limited face-toface socialization opportunities with peers, which are especially important in the teenage years, and worries about the pandemic health results in general. At the same time, students had to continue to fulfil their academic responsibilities and meet academic requirements (Singh et al., 2020; Scott et al., 2021; Hacatrjana, 2021). The impact of COVID-19 on the psyche of young people was characterized by several conditions, including also the direct psychological consequences of the pandemic (i.e. fear, fake news, the consequences caused by the restrictions of the pandemic (lockdown, etc.) and the consequences directly related to COVID-19 (i.e. the death of a loved one, side effects). During the pandemic, young people had limited socialization opportunities, leading to loneliness and anxiety. Loneliness and anxiety are known to be associated with psychological difficulties (Loades et al., 2020).

In various studies, students have reported psychological difficulties (e.g. depression or lack of motivation, feelings of anxiety and difficulty concentrating on work) or physical health problems (e.g. back pain when sitting at the computer, eye pain and other difficulties) (e.g. Hacatrjana, 2021; Belousova, Mochalova, & Tushnova, 2022).

Young people were also asked what would be needed to reduce mental health problems. 60% indicated the need to spend more time with friends, 48% of young people would benefit from physical activities and sports, and 38% would like to receive consultations from a psychologist or psychotherapist.

The impact of COVID-19 on the emotional and psychological well-being of young people is very important, as research shows that half of all mental health problems appear before the age of 14, and threequarters of all mental disorders appear before the age of 24 (Mittendorfer Rutz & Wasserman, 2004). This is related to rapid changes in the body (e.g. growth, hormones). During this period, the limbic system is very active, the frontal lobe is still maturing, and identity formation is essential for development (social contacts, separation from parents, etc.)

Although COVID-19 is no longer an issue, young people studying remotely during the pandemic are now our learners. Therefore, this study aims to identify the emotional state of youth at school (general, professional, interest) at the moment and the impact of COVID-19 on their emotional and psychological well-being.

#### **Materials and Methods**

The theoretical basis of the research methodology is based on the considerations above and the World Health Organization's definition of health (WHO, 2001). The understanding of mental health emphasizes the focus on well-being and considers positive mental health as 'a state of well-being in which the individual realizes his or her abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to contribute to his or her community'.

The emotional and psychological well-being of learners is therefore important for the sustainability of the learning process. Thus, 16-23-year-old school youth (general, vocational and special interest education) were part of the empirical part of this study aimed at identifying their emotional state as well as teachers survey to identify the impact of COVID-19 on their mental health 'Figure 1'.



Figure 1. The design of the study.

The survey was carried out within the Nordic Council of Ministers' Grant Programme Nordplus project 'Methods for working with young people to ensure learning process resilience' in six different educational institutions (general, vocational and interest education) from three Baltic states. In total, 859 learners and 176 teachers took part in the survey.

Based on the above theoretical considerations and using the methodology of the study on the mental health of the post-pandemic generation of engineering students (Vintere & Balode, 2024), the two questionnaires (for students and teachers) were designed, characterized by the following keywords:

- Conversation with classmates, communication difficulties (peers, parents, teachers), social environment;
- Routine (day/night), leisure, free time activities,

hobbies, physical activities;

- Routine (day/night), leisure, free time activities, hobbies, physical activities, feelings, bullying, workload, competition;
- Problem-solving strategies, solutions (what do they need), motivation aspects, support, and help they need. The student questionnaire (in English) is still available here https://forms.gle/SBT8BjGk9PS9cvdE seven and the teacher questionnaire https://forms.gle/Wr99Zh QzsA7KZbPm6. The questionnaire was distributed among students aged 16 23 and teachers through the school e-learning systems.

The quantitative results of the study were analysed using descriptive statistics, while content analysis was used for qualitative data obtained from open-ended questions.

#### **Results and Discussion**

In the first question of the survey, students assessed their emotional well-being on a scale from 1 to 10: 1very bad, 10 - excellent. The results are similar in all Baltic States, and '7' is the most frequently repeated answer. It is alarming that, although a small minority, some learners rate their emotional well-being only between 1 and 3.

The second question asked learners to tick their feelings recently: angry, tired, happy, self-confident, safe, calm, anxious, worried, guilty and free answer – other. The results are similar – students feel tired, restless, anxious and angry. Comparing results by country, it should be noted that Estonians feel more self-confident and much calmer. Also, Estonian students seem to have more sense of safety when rating their sense of safety on a scale of 1 to 10 (1 - very bad, 10 - excellent).

Comparing the answers of students and teachers to similar questions, teachers are very optimistic and, for example, do not see anxiety or eating disorders as a big problem 'Figure 2', 'Figure 3'.



Figure 2. Anxiety.

In addition, students in vocational schools are more likely to have eating disorders than those in gymnasiums or afternoon schools (in the so-called interest educational institutions).

Students were also asked if they experienced bullying

in their environment. There are differences between types of schools, with vocational school students being the most likely (14%) to experience this.

However, bullying is also experienced by gymnasium students (11%) but is least common in afternoon schools - only 3.2% of cases were affirmative.

Student answers to the question, 'How do you feel about your workload?' (Table 1) shows that almost half of the respondents' workload is heavy, one of the most important causes of anxiety in schools today.



Figure 3. Eating disorders.

Table 1

#### Student answers, 'How do you feel about your workload? '

Type of school	It is too heavy	It is adequate	It could be heavier
Gymnasium	45.3%	51.2%	3.5%
Vocational schools	40.2%	50.5%	9.3%
Afternoon school	48.4%	48.4%	3.2%

The teacher survey included similar questions. To the question, 'Which of the following mental health problems have occurred/ exacerbated in your students since the pandemic?', teachers as the first most identified excessive use of the computer or social networks, second - difficulties, third – irritability. For vocational schools, it is also very problematic despair depression. Teachers were asked to mark the three most important

areas where their students have significant difficulties. Results show that studies/work, physical health, and physical activities / sports are the three most important difficulties students face after the COVID-19 pandemic (Table 2).

Students were asked what kind of help would be most beneficial to them and were asked to tick one or more of the answers given (Table 3).

Table 2

The teacher answers.	'In which	areas do vou	r students have	e significant	difficulties?'
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	Vocational schools	Gymnasium	Afternoon school
Studies/work	83%	78%	69%
Free time/hobbies	23%	28%	31%
Physical activities/ sports	40%	43%	38%
Friends	9%	18%	8%
Romantic relationships/ sexuality	6%	7%	0%
Physical health	49%	38%	23%
Finance	9%	4%	0%
Relationship with parents	20%	25%	31%
In none of these	6%	5%	0%
Other	3%	3%	0%

Table 3

Students' answers about the help that would be most useful

	Vocational schools	Gymnasium	Afternoon school	
More time with friends	20%	30%	38%	
Physical activity or sports	71%	72%	85%	
Psychological counselling	46%	40%	31%	
Help with studies	63%	48%	62%	
Joint activities with the family	14%	41%	8%	
A conversation with an important adult outside the family	34%	38%	62%	
I need support, but I don't know what type of it	17%	2%	0%	
No support is necessary at this time	6%	14%	0%	

Results show that physical activities or sports and help with studies would be most helpful to students. Psychological counselling or psychotherapy would also be beneficial for gymnasium and vocational school students, but afternoon school is a conversation with an important adult outside the family.

A similar question was also asked of teachers: 'What do young people need most to reduce mental health problems?'. Table 4 summarizes students' and teachers' answers by type of school.

Table 4

reachers answer, what do young people need most to reduce mental health problems:							
	Vocational schools		Gymnasium		Afternoon school		
	Teachers	Students	Teachers	Students	Teachers	Students	
More time with friends	20%	36%	30%	56%	38%	48%	
Physical activity or sports	71%	38%	72%	34%	85%	39%	
Psychological counselling	46%	21%	40%	28%	31%	35%	
Help with studies	63%	27%	48%	29%	62%	32%	
Joint activities with the family	14%	20%	41%	21%	8%	23%	
A conversation with an important adult outside the family	34%	9%	38%	12%	62%	3%	
I need support, but I don't know what type of it	17%	29%	2%	19%	0%	6%	
No support is necessary at this time	6%	18%	14%	21%	0%	23%	

#### Teachers answer, 'What do young people need most to reduce mental health problems?'

Teachers in all types of schools claim that physical activity, sports and help with studies could reduce mental health problems. There are differences in the answers of pupils of different kinds of schools. For example, young people from vocational schools say that the help they need now is physical activity and sport, as well as more time with friends, but 29% - say that no support is needed

at this moment. At the same time, it is essential for gymnasium and afternoon school students to spend more time with friends, follow physical activity and sport, and help with studies; for afternoon school students in the third place - psychological counselling and psychotherapy - a comparative teachers and students answers' summary given in Table 5.

Table 5

	Teachers	Students
More time with friends	29%	49%
Physical activity or sports	73%	36%
Psychological counselling	40%	26%
Help with studies	52%	29%
Joint activities with the family	33%	21%
A conversation with an important adult outside the family	39%	10%
I need support, but I don't know what	5%	22%
No support is necessary at this time	11%	20%

The most helpful help for students at the moment would be more time with friends (49%), physical activity or sports (36%) and help with studies (29%). Teachers believe that for promoting students'

#### Conclusions

- 1. When evaluating students' emotional well-being on a scale from 1 to 10: 1 - very bad, 10 excellent, '7' is the most frequently repeated answer.
- 2. There is a correlation between emotional wellbeing and a sense of security. Young people in all types of schools rated feeling safe higher than emotional well-being, as demonstrated by students answers to the questions 'Evaluate your emotional well-being on the scale' and 'Tick the feelings you have been having recently'.
- 3. The main problem for students in all types of educational institutions in the Baltic States is tiredness.
- 4. The exact number of students rate their workload as 'It is adequate and 'It is too heavy'. The results show that the emotional well-being score is lower than the sense of security score for students who

emotional and psychological well-being, young people need most physical activity or sports (73%), help with studies (52%) and psychological counselling or psychotherapy (40%).

answered 'It is adequate' and 'It is too heavy' about the workload.

- 5. There are differences between the types of schools on the question of whether their students have experienced bullying in their environment: vocational school students experience it most often (14%), gymnasium students - 11%, but it is the least in the afternoon schools - only 3.2% of cases were affirmative.
- 6. Comparing the answers of students and teachers to similar questions, teachers are very optimistic. For example, teachers, unlike students, do not see anxiety or eating disorders as a big problem.
- 7. Teachers' and pupils' answers to reducing mental health problems differ slightly. For students, it is most important to spend more time with friends, engage in physical activity or sports, and help with their studies. At the same time, teachers think that young people need most physical activity or sports,

This study uses data from the Nordic Council of

Ministers' Grant Programme NORDPLUS project NPJR-2022/10195 'Methods for working with young

people to ensure learning process resilience'.

help with studies, and psychological counselling or psychotherapy.

8. Reduced workload, learning support, physical activity and sporting opportunities are measures to improve pupils' emotional and psychological well-being.

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# DEVELOPMENT OF PROFESSIONAL COMMUNICATIVE COMPETENCES OF STUDENTS'

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#### Abstract

In our republic in the process of preparing students for professional activity one of the urgent tasks is considered to be the development of their professional speech. It is very important for today's specialist to be competent, competitive and able to communicate effectively in his future activity. However, the main problem is the teaching of professional culture and the holistic development of professional communicative competences. The aim of the article is to develop recommendations and methodological guidelines to ensure the cultural communication of future professionals. In particular, the experiment proves that the student should feel the benefit of learning a foreign language in the future and get used to independent work on the subject, and gradually the motivation to learn the language will appear. The study highlights the role of foreign language teaching in the interdependence of 'language - communication - professional - culture', the interdependence of language and culture in the development of language skills, the systematic approach to the study of professional terms. It is a well-known fact that students, in addition to acquiring lexical and grammatical knowledge of a foreign language, should also have a perfect command of the culture and values of their country and of the country where the language is learnt. In order to effectively implement the business communication in the classroom, it is desirable for the student to 'understand the foreigner', to study and master the culture of the foreign country, the accepted rules and values. While doing research, the methodological recommendations and instructions for the systematic organization of foreign language teaching are given.

Keywords: English for Specific Purposes, professional communicative competence, communication, business situations.

#### Introduction

Recent developments in Uzbekistan's socio-economic landscape, political environment, and its integration into the global community have enhanced international relations and fostered connections among individuals of various nationalities across management, business, economic, social, and political domains at multiple levels. In today's globalized society, contemporary educational settings should prioritize the cultivation of personal intellectual capabilities, critical thinking, and communication skills, which are vital for appreciating cultural diversity and collaborating with representatives from a range of multinational organizations.

Enhancing professional communicative competence equips graduates from Uzbek economic universities with a competitive edge in the international finance job market. One of the key objectives of the targeted program for Research and Development in Priority Areas of Advancement in Uzbek Scientific and Technological fields is to align higher education curricula with global market standards and requirements. Achieving this goal necessitates the adoption of contemporary learning methods, while the application of a competence-based approach is equally significant in today's educational landscape. In the process of professionally-oriented foreign language education, all goals and tasks should be oriented to the professional development of communicative competence of students. The President of the Republic of Uzbekistan Shavkat Mirziyoyev - posited that any meaningful advancement in a field is contingent upon the practical application of scientific achievements and innovative technologies. These tasks include the training of personnel with extensive and up-to-date knowledge, the improvement of their qualifications,

and the assimilation of foreign experience. In order to achieve these goals, it is essential to improve the quality of education in higher educational institutions specializing in the agrarian sector. Furthermore, it is crucial to establish close cooperation with prestigious educational institutions of developed countries, to improve the activities of scientific institutions in the field of seed production, and to enhance the breeding and veterinary affairs. The aforementioned tasks are currently underway (Mirziyoyev, 2022).

A novel approach to the training of professionals from various fields and their personalities is a prerequisite for modern social development. Professionals in this field must possess critical thinking, independent problemsolving abilities, the capacity to innovate, and communicative competence. It has been demonstrated once again that innovation itself is about collaboration. When an innovation is successful, it is based on foreign experience, taking into account national conditions. It can be concluded that a specialist who is fluent in foreign language, information and communicative communication and knowledgeable in their field can engage in intercultural communication and competition. This will lead to improvements in the economy, an improvement in people's welfare and the completion of useful work in all respects. Consequently, this vision should be instilled in the younger generation. It is important to recognize that time is of the essence in integrating professionalization, competence and specialization (Ilieva, 2020).

The credit-module system revealed certain factors that impede the holistic development of students' professional communicative competences. The inadequate pedagogical conditions for the lack of sufficient formation of psychological aspects such as cultural communication have a negative impact on the quality of education. It has been demonstrated that intellectual, cognitive, and volitional qualities are essential for the participation of future specialists in international professional activity.

It can be demonstrated that the effectiveness of the developed rules of statistical processing of experimental testing results, improvement of students' professional and cultural training, integrative and creative teaching of English in the credit-modular system, and improvement of professional training can be evidenced. Furthermore, the development of foreign language teaching materials on a credit-modular system for the national audience based on foreign experience and presented with the help of modern technologies has been shown to result in increased student motivation, language development, and the acquisition of social, cultural, and professional competencies.

The study highlights the role of foreign language education in the interdependence of 'speech communication - profession - culture', the interdependence of language and culture in the development of speech competences, the systematic approach to the study of professional terms. New in the process of training specialists of various fields and their personality approach is a necessary requirement of modern social development. Professionals in this field, capable of competing, need critical thinking, independent problem solving, ability to innovate and communicative competence.

It has been confirmed once again that innovation is linked to cooperation. An innovation is successful when it is based on foreign experience and takes into account national conditions. To achieve high results in the future and become competent, a specialist must learn foreign language well in addition to their field. This will enable them to make independent investments at home and pursue a career in their chosen field. It is concluded that a specialist who is proficient in foreign language, information and communicative communication, and their field can engage in intercultural communication and competition. This can lead to an improvement in the economy, people's welfare, and useful work in all respects. Therefore, this should be the vision for the young generation. It is worth noting that time demands the integration of professionalism, competence, and specialization (Ilieva, 2020).

# A competence-based approach in development of professional communicative competence

The traditional Uzbek education system, which consisted of a fixed number of classroom hours and a specific list of subjects, has been overhauled and replaced with a new model that utilizes a standardized credit system commonly found in European education (Frolova *et al.*, 2016).

The ability to make decisions and work flexibly are key priorities in contemporary Uzbek education. There's been a noticeable transition from a focus on knowledge to one centered around competencies. Irina A. Zimnyaya points out several reasons for emphasizing a competence-based approach and the necessity of integrating this approach into the educational system, including:

- trends of European and global integration as well as the globalization of the world economy;
- shifts in educational paradigms;
- standards established by local education authorities (Zimnyaya, 2004).

A key distinction between the competence-based approach and the traditional knowledge-based model is its emphasis on reflective assessment and an awareness of the limits of professional competence. The competence-based approach connects the educational process with understanding, fostering students' professional identity and a positive attitude toward learning. The central concept of this approach is that simply acquiring isolated facts and skills isn't the primary goal of higher education; instead, it focuses on an individual's ability and readiness to perform effectively in various situations. Furthermore, many universities today are adopting the competencebased approach by employing active and interactive teaching methods, such as business meetings, roleplaying, case studies, and psychological training sessions (Vasbieva & Kalugina, 2016).

Transitioning to a competence-based education system offers advantages for both students and teachers:

- it defines clear performance standards for teachers and students, allowing for better decision-making and enhanced effectiveness in their efforts;

- it equips students for active participation in society, encourages lifelong learning, fosters independence, and promotes self-education and reflection;

it fosters a mutual understanding of what proficiency entails when students exhibit it, along with more relevant feedback on what they need to do to advance;
it establishes dependable two-way communication between teachers and students.

# Components of professional communicative competence

Many Uzbek scholars have made significant contributions to the evolution of this concept. Below, we will highlight a few of these scholars whose theoretical insights and empirical research have notably influenced the field of professional communicative competence.

I.V. Novgorodtseva professional-communicative competence is characterized as a personal attribute. It encompasses the skills, abilities, and knowledge required for effective communication, as well as the individual personality traits essential for addressing challenges in a professional setting (Novgorodtseva, 2008). According to the scientist professional-communicative competence contains the following components: motivational, cognitive, technological, personality, reflective.

M.A Erofeeva, O.A. Zhelnova understood profess-sional communicative competence as an integrative pattern of personality traits, the unity of the professional culture and the necessity of professional knowledge, skills and competence (Erofeeva, Zhelnova, 2011). In their opinion the structure of professional communication competence consists of professional and socio-cultural knowledge, profess-sional communication skills, personality values and motivation.

According to E.B. Solovyova, professional communication competence contains particular personality traits (empathy, kindness, tolerance, sociability, responsivity); professional communication skills (knowledge of community speech norms, business etiquette, ability to use appropriate communication patterns); communication skills (ability to start a conversation, develop your ideas and finish your speech effectively, dominate the conversation and outcome, consider the fluency) (Solovyova, 2001).

B. Ospanova, T. Timokhina and N. Kassenova highlight the key structural elements of communicative competence:

- a linguistic competence;
- a sociolinguistic competence;
- a discourse competence;
- a strategic competence;
- a sociocultural competence;
- a social competence

(Ospanova, Timokhina, & Kassenova, 2013).

All these concepts are characterized as the knowledge and skills required for practical application. This indicates that scholars, particularly in the realm of applied linguistics, have come to a consensus after extensive theoretical and empirical studies on professional communicative competence. They agree that an effective language user must not only have knowledge of the language but also the ability and skill to utilize that knowledge in communication scenarios. Nonetheless, while defining, observing, and assessing foundational knowledge that constitutes the communicative competence relatively is straightforward, comprehending, describing, and evaluating the capacity for practical application is more complex (Bagarić & Djigunović, 2007).

Thus, professional communication competence can be described as a multifaceted and dynamic system that combines personal and professional skills. This enables finance professionals to effectively engage in communication activities aimed at addressing communication challenges within the financial sector (Vasbieva & Kalugina, 2014).

This learning process has its own emphasis and priorities and is an effective way of teaching a foreign language. ESP is an approach to teaching a foreign language where all aspects of teaching, including content and methods, are based on the students' motives for learning. The focus is on the goal for which students learn the language, rather than the linguistic features. In practice, distinguishing between GE and ESP can be challenging during the foreign language learning process. ESP relies on the common and scientific base of the English language. Effective teaching of ESP requires identifying its specifics, which primarily involves updating, expanding, and deepening students' basic language skills (speaking, reading, listening, writing) based on the material of their specialty. The teacher of the ESP course must not only be an English language specialist, but also possess knowledge in the field of special disciplines that underlie the students' future profession. The problems of language for special purposes are multifaceted and limitless, requiring a synthesis of various methodological aspects. It is clear that expertise in this area is essential for success. The problems of language for special purposes are multifaceted and limitless, requiring a synthesis of various methodological and purposes are multifaceted and limitless, requiring a synthesis of various methodological and linguodidactic aspects as well as the theory of intercultural. The students' motives for learning foreign language.

Thus, the focus of teaching a foreign language is the goal for which students learn the language, and not the linguistic features. In practice, in the process of learning a foreign language, it is sometimes difficult to clearly distinguish between GE and ESP. It should be noted that with all its specificity, ESP cannot but rely on the common and scientific base of the English language.

Therefore, for effective teaching of ESP, it is necessary to identify its specifics, which consists, first of all, in the fact that the basic language skills (speaking, reading, listening, writing) of students are updated, expanded and deepened based on the material of the specialty. Hence, the teacher of the ESP course must not only be an English language specialist, but also have knowledge in the field of special disciplines that underlie the students' future profession (Murtazaeva, 2023).

From this we can conclude that the problems of language for special purposes are very multifaceted and limitless. It includes a synthesis of various methodological and linguodidactic aspects: lexicology, the theory of intercultural communication, functional stylistics of speech, interdisciplinarity and, of course, the availability of trainees (Djumaniyazova, 2024).

The role of foreign language in the development of their professional competences is incomparable in the training of industry specialists who are able to participate in the competition, which is considered to be relevant at the moment, including in the field of agriculture. In co-operation with developed countries. the future specialist must first of all master his/her field, master a foreign language, especially English at a sufficient level (communication and culture are taken into account), develop international co-operation, IT (Information Technology). The period requires the acquisition of necessary information. At this stage, it is necessary to organize the integration of a number of subjects taught in higher education institutions. This integration is based on the strengthening of mutual cooperation, i.e. industry experts + professors and teachers of foreign language (EMI/English as a medium of instruction) + employer + creation of interdependent IT programs and plans, it is advisable to establish communicative relations, solidarity, unity during training in production companies, during the internship period or in the laboratory.

#### Materials and Methods

In the course of the research, the documents of nonphilological educational institutions on the problem were studied, analyzed and instructions were given. The process of English language teaching was observed with the help of research methods, including lesson analysis and a comparative method based on the achievements of information technologies. Questionnaires and interviews were conducted, as well as an experiment-test, test, and mathematical statistical methods were used.

The main purpose of the course 'Foreign Language (Academic and Technical Communication in English/German)' for students studying at Tashkent Chemical Technological Institute is to prepare students to effectively use a foreign language in everyday life, scientific and professional activities. Such an approach enables students to cultivate a sense of patriotism, logical thinking, independent research skills, knowledge and skills, the ability to prepare and conduct presentations on universal and industry-specific topics, the capacity to write scientific articles and so forth.

The analysis of the academic literature indicates that professional communicative competence must be integrated and multi-dimensional, featuring a complex structure.

- A sociolinguistic competence (SLC) implies the ability to select and to use adequate linguistic forms and means depending on the aim and situation of communication, social roles of communication participants;

- a discourse competence (DC) implies the ability to understand various types of communicative statements, to build integrated, coherent, logical statements of various functional styles (Ospanova, Timokhina, & Kassenova, 2013);

- an acme logical competence (AC) reflects priorities of personal achievements of high level of professionalism through communication (includes determination, emotional stability, reflective thinking and empathy);

- a foreign language competence (FLC) deals with knowledge of the foreign language and the ability to use that knowledge to interpret and produce meaningful texts appropriate to the situation in which they are used. It is best developed in the context of activities or tasks where foreign language is used for real purposes, in other words, in practical applications, see 'Figure 1'.



Figure 1. Professional communication competence structure of higher schools' students. Professional communication competence levels.

The levels of professional communication competence, as outlined by the current research methods and theoretical insights, can be classified into low, medium, and high-performance levels, following the framework established by the INCA project, and the Interagency language roundtable skill level descriptions for intercultural communication.

At the low proficiency level, learners demonstrate suitable posture and behavior during brief polite exchanges, such as greetings and farewells, but struggle to handle unexpected situations. They often miss signs of miscommunication and typically cannot resolve misunderstandings when they arise. They generally find it challenging to engage in less predictable or spontaneous interactions, like openended discussions or negotiations. At the medium proficiency level, learners can express opinions on abstract topics in a limited manner, offer advice within familiar contexts, and comprehend instructions or public announcements. They are capable of writing letters and taking notes based on predictable needs. At the high-performance level, known as the analytical level, learners can effectively participate in meetings related to their field of work, maintain casual conversations with considerable fluency, manage abstract expressions, and confidently respond to challenging questions. They can comprehend documents, correspondence, reports, and including nuanced aspects of complex texts, and are proficient in writing letters on any topic and accurately taking comprehensive meeting notes. Therefore, it is crucial for learners to develop medium to high levels of sociolinguistic competence, discourse competence, logical reasoning competence, and foreign language proficiency. Consequently, there is an urgent need to implement innovative technologies in the educational process, emphasizing a strong interaction between theoretical and practical learning forms that align with contemporary educational demands.

The program defines educational outcomes, including the development of skills and competencies in oral and written expression on topics related to socio-cultural and domestic activities. It also aims to enable students to use all language skills orally and in writing for effective professional communication and cooperation. Additionally, the program seeks to instill in students the ability to learn terms and terms used in scientific and professional activities. Furthermore, it aims to cultivate in students the capacity to work independently on scientific and branch topics, etc. For example, the content of the program which is aimed to train specialists on management, business, economy and technology. Vocabulary development is also a key component of the program, with students expected to gain proficiency in professional language. Reading and speaking skills are also developed through the program, with a focus on lexical words. It also includes writing exercises and assignments for independent study. For instance, an excursion to industrial enterprises of the republic.

In an interview with the chief management about production productivity at the enterprise, preparation of a dialogue on the topics 'Interview with the head of the enterprise about employment', etc. English for Specific Purposes (ESP) educational program includes its own verbal topic, means of expressiveness language material, community participants (interactors) and others.

The methodological approach of ESP originates from the English for Science and Technology (ESP) system (Swales, 1985). ESP is a necessity in situations where an individual is required to communicate in a particular context, such as when speaking with customers or colleagues in any industry.

According to Sokolova, the modular organization of the educational process for the development of professional direction of management and business communications in a foreign language forms the communicative competence of a specialist. Skills and competences used to solve complex professional problems in business a) remote communication situations: (written communication), b) oral communication in situations of high professional responsibility (presentation, discussion, agreement, etc.), c) development of personal qualities, knowledge and skills of cooperation and communication with representatives of other cultures. Subjects should have the ability to carry out professional activities at a sufficiently high level, to study and master the rules of a foreign language in order to predict its development and avoid mistakes that lead to communication failures (Sokolova, 2007).

At all stages of English language teaching, modern advanced methods, techniques and tools, forms of language teaching, all terms and concepts related to science should serve to optimize and accelerate the learning process. This is undoubtedly due to its communicative and professional orientation, to the independent work of the students in the classroom, at home, in the laboratory, outside the classroom, as well as to the constantly increasing techniques of work applied in the classroom (in pairs, in groups or in individual performance). This is carried out through situational roles to the extent that the language learnt is appropriate to the requirements of the time. Teaching and methodological complexes based on the formation of communicative and methodological skills of a future professional are an integral part of oral and written language teaching. These are textbooks, workbooks, dictionaries, audio and video materials used for the transition and completion of a given topic. Creative tasks in the field (experimental laboratories, warehouses, garages) should include:

- the development of safety rules and a comparison of these with existing ones, with an explanation of the differences (formulate safety instructions in the field (experimental laboratories, warehouses, garages) and compare the instructions with existing instructions, explaining the differences);
- in order to gain an understanding of the most

consumed agricultural products among the population, a social survey should be conducted. This information should then be discussed in a group setting. The integrated presentation of exercises and assignments in the classroom, which covers relevant and necessary current issues related to the foreign language and the profession and field, with effective use of interactive and innovative methods, further enhances the quality of education (Holiyorov, 2021).

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#### **Results and discussion**

We identified the following as key factors in the development of students' professional communication skills:

- the globalization of education and academic mobility;
- the need for knowledge of foreign languages and communication at a cultural level in order to broaden students' professional activities and communicate with representatives of different countries;
- awareness and independence in making responsible decisions;
- the introduction of information technologies in professional activities;
- the need for continuous improvement of education and qualifications in order to maintain the competitiveness of professionals in the global market.

Znikina notes that, professional communication skills are provided by as an additional functional support system for professionals:

- national functions of a specialist, expressed in willingness and abilities;
- organization of communicative activities in various professions;
- organizing communication with groups and representatives of different cultures;
- understanding the manifestation of the level of professionalism in professional activity;
- achievement of goals through the national professional communicative skills of the specialist, which provides an effective choice of actions (Znikina, 2005).

The main objective of the model which is recommended by Tomareva is to direct the educational process towards a) understanding of the other culture and oneself in the dialogue of cultures; b) spiritual upbringing of students on the basis of the new culture in dialogue with their national culture. In other words, the new culture is learnt in comparison with the local culture known to the students. Achievement of purely pragmatic goals - to quickly raise the cultural level of students / future managers, to teach them the rules of speech communication, to teach them to communicate in their native and learnt languages, to control speech generation and interaction - to teach them how to use it as a means of concealment (Tomareva, 2006).

The development of academic and professional communication of students in a foreign language, the gradual transfer of the educational process in higher educational institutions of our republic to the creditmodule system in recent years, ensuring academic mobility of students, expansion of independent learning, normative base of education to raise the content and quality to the international level. Intellectual, cognitive and volitional qualities are necessary and important for the future specialist to participate in international professional activity.

As a result of our research, we have developed a structure for improving student learning activities. According to this project, the improvement of students' educational activities was studied in two stages. In particular, in the static stage, the Educational methodological support and its components (educational and methodological support, subject program, syllabus, textbook, study guide, exercises and text), in the dynamic stage educational process (workshop/ lesson, independent study, activities, training, current/ intermediate/ final controls) is reflected. Statics and dynamics are used in all fields, including physics, medicine, culture, art, and others (Majidova, 2023).

#### Conclusions

Additional studies on the enhancement of professional communicative competence will involve a more precise definition of what this competence entails, examining its various developmental stages, and identifying effective methods for achieving a high level of proficiency. In the 21st century, professional communicative competence is essential and plays a critical role in shaping students' mindset and character. The aforementioned conclusions have been reached as a result of our experimental work, research and longterm observations.

The advantages of foreign language is manifest in the following ways: (1) the students' memory is strengthened, as are thinking, speech, talent and culture; (2) the competitiveness of personnel is improved; (3) a specialist who is fluent in a foreign language was able to learn foreign experience independently; (4) as a result, they became fluent in communicating with partners, etc. The research conducted on the teaching and learning of foreign language within the Credit-modular system resulted in the following conclusions:

1. The current stage of foreign language teaching in higher institutions of chemical-technological direction is analysed, the expediency of choosing the content of education and establishing processes of interdisciplinary cooperation is shown.

- 2. The peculiarities of foreign language teaching, i.e. the identified problems are the shortage of teaching hours, insufficient provision with teaching materials, technical means (in rural areas), slowness of aspiration to master the language of students and the teacher should remember of all them.
- 3. Suitable for specialisation in a foreign language in the field of management, business, economy and education. According to the results of the analysis of the need for training without ESP, future specialists should be able to carry out professional communicative competences (can-speak), critical thinking, communication, group work and information exchange. Critical thinking method is developed on the basis on individual, pair, group and share.
- 4. In educational institutions in the implementation of experimental work, it is proved that the materials, exercises and tasks for teaching the terms related to the field were selected correctly and the training organised on the basis of integrative approach showed effectiveness.
- 5. The linguodidactic bases of the development of the culture of professional communication in a foreign language have been studied and analysed.
- 6. Methodological recommendations for the systematic organisation of language training of the profession have been developed.

Based on the aforementioned findings, recommendations and suggestions for enhancing the educational activities of students at higher education institutions were formulated. These included:

- 1. The development of a new educational literature designed to facilitate the acquisition of professional communicative competencies by students within the credit-modular system.
- 2. The strengthening of international cooperation, the organisation of seminars and training programmes that contribute to the development of students' professional communicative competencies.
- 3. To enhance their professional competence by organising a range of socio-cultural events, competitions and practical projects in which students can participate directly.
- 4. Preparation of training manuals and textbooks describing the characteristics of business cultures and improving them in accordance with the requirements of DTS based on the best foreign experience of social and cultural content.
- 5. Development of methodological recommendations, scientific and practical approaches to apply a systematic approach to improve the communicative and professional competences of students.

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## THE DEVELOPMENT OF STUDENTS ORAL SPEECH USING PROBLEM-BASED LEARNING SKILLS

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#### Abstract

In the world practice, scientific research is aimed at the development of oral knowledge, skills and abilities in teaching English. The technical higher educational institutions and the integration of skills in teaching process are being conducted. The English language proficiency is becoming increasingly important for academic success. English is one of the compulsory subjects in the school curriculum, and it is taught in all disciplines, including teacher training, vocational, science, engineering, and technology. The aim of the article is to substantiate how to teach students to develop oral speech using problem-based learning and to strengthen their knowledge in the fields of engineering, management, and business spheres, to increase the effectiveness of oral speech in English, and how to effectively use Problem-based learning skills (PBL) in the technological processes. Results show the important aspects of Problem-based learning method in today's modern educational environment, the development of critical thinking, independent and creative skills of learners, the further development of the mental activity, the search for various solutions to problem situations, effective methods of problem-based education, general information about its importance and features are given.

Key words: problem-based learning, problematic situation, knowledge acquisition, speech methods, speaking skills.

#### Introduction

Problem-based learning (PBL) is a new system that uses logical thinking, analysis, research, generalization, problem situations, finding solutions, curiosity, needs, and methods that is why the aim of the study was to substantiate how to teach students to develop oral speech using problem-based learning and to strengthen their knowledge in the fields of engineering, management, and business spheres. PBL is a student-centered method where students solve open-ended problems in groups to gain knowledge about a subject. This issue is what drives the motivation and learning. Problem-based learning is a useful teaching tool in today's high schools. Its job is to form a scientific research method of thinking and promote the process of active learning. Instead of presenting facts and concepts to students directly, Problem-based learning (PBL) uses intricate realworld problems as a means of fostering their understanding of concepts and principles. PBL can help students develop their critical thinking, problemsolving, and communication skills in addition to the course material. Additionally, it can offer chances for group projects, locating and assessing research materials, and lifelong learning (Duch et al., 2001).

Hung introduced the 3C3R model as a conceptual framework for systematically designing optimal PBL problems. PBL is an instructional method that drives all learning via solving an authentic problem. The idea of 'basics first' goes out the window in PBL; rather, one learns the basics in the context of a meaningful, but ill-structured problem-solving activity. A cohesive body of research is beginning to show the effectiveness of PBL (Hung *et al.*, 2008).

Problem-based learning (PBL) is perhaps the most innovative pedagogical method ever implemented in Education. Its effectiveness in facilitating student problem-solving and self-directed learning skills has been widely reported in medical education (Barrows & Tamblyn, 1980). Although such a statement may appear self-evident, this assumption is in conflict with our public education system, which primarily implements learning only in formal education settings perhaps implying that once we leave school, we cease to learn. Problem-based learning has its implementation roots in the field of medical education starting in the 1950s (Savery & Duffy 1995).

Hung also reported, a related perspective posits that PBL has its roots in theories of situated learning (Hung, 2002).

Jonassen concluded that, fundamentally, PBL is based on constructivist assumptions about learning. Constructivism can be described in terms of five tenets about knowledge, meaning making, and learning (Jonassen, 2004).

As we engage in learning, community and their beliefs and values influence communities (such as the interactions among learners in a PBL environment), our knowledge and beliefs about the world. For instance, our knowledge of the world is influenced by the activities in which we engage at work. The beliefs and knowledge of our fellow practitioners or learners influence our thinking. Duffy and Cunningham (1996), then, see learning, as changes in one's relation to the culture(s) to which one is connected. Our knowledge and belief are distributed among the participants in these communities (Salomon, 1993). This interaction and interdependence are played out particularly in PBL, as learners rely on the experiential knowledge of other team members to help accomplish tasks or articulate beliefs or stances needed to solve the PBL problem.

Although all of these studies may be helpful for understanding what PBL problems should contain, faculty-implementing PBL may still find this work lacking in specificity. Major and Palmer offer that those implementing PBL should consider two techniques for problem improvement: outside evaluation by experts and content analysis of projects (Major & Palmer, 2001).

The study identified that the two most important criteria were that the problem should stimulate thinking or reasoning and lead to self-directed learning in students. Sockalingam and Schmidt characterize the problems for Problem-based learning (Sockalingam & Schmidt, 2011). Students identified eleven characteristics, of which they found the extent to which the problem leads to desired learning outcomes as the most important characteristic. The extent to which the problem stimulates elaboration and the extent to which the problem promotes team effort were considered to be the least important problem characteristics.

Akhmedova says some information in her dissertation where the essence of concepts like Problem-based learning, problem solving as a learning principle, problem-based methods, problematic task problematic problematic question, task. and problematic situation revealed, the categorical apparatus of problem-based learning technology finds it is largely exhaustive description considering that we accept the definitions in their entirety (Akhmedova, 2012).

Problem-based teaching corresponds to the goals of creative and active personality education. Problembased teaching has a great potential in revitalizing students' cognitive activity in conscious and solid acquisition of knowledge, determining their active attitude to the environment. In problem-based teaching, the teacher organizes the students' cognitive activities, so that the students independently solve intellectual problems based on the analysis of subjects, draw conclusions, generalize form laws, and apply the acquired knowledge to a new situation.

When we talk about the problem-based education in pedagogy, the first thing that comes to mind is oral, demonstrative and practical methods. Each of the verbal, visual or practical methods of education can create a problem situation in the student's mind. Problem situations, in turn, lead the students to independent thinking, reflection, research, and creativity, in other words, to the growth of his mental potential. In today's era of globalization, the problem approach should find its expression in educational programs and independent activities of students including problem statement of knowledge, encourage students to search, research method of education.

Problem-based education means imparting information to learners in a way that is appropriate to their level and creates problems. Only when education is conducted in this direction, problem situations arise in the students thinking activity, and they encourage them to objectively search, think, and learn to make logical scientific conclusions.

Problem-based education is a subjective form of expressing the need to develop scientific knowledge. A situation objectively arises between knowledge and ignorance in the process of the development of a new society. A problem situation is a certain mental state of the student, which arises due to the realization of a conflict in the process of performing a certain task. The 'Problematic situation' method is designed to help students develop the ability to examine the causes and effects of difficult situations, identify multiple solutions, and determine which conclusion is the most appropriate.

First, the difficulty of the problem selected for the 'Problem Situation' approach ought to match the students' level of understanding. When choosing problematic situations, the age and level of education are important. Students must be able to solve the provided problem. If they cannot do so, they will become disinterested and lose confidence. The fundamental aspect of problem-based learning is how teachers guide the cognitive processes to learn new material by posing problems in their assignments and helping them find answers to questions and tasks. This establishes scientific research methodology for knowledge acquisition.

In the classroom teachers do a significant role, but students should also take charge of learning. This shift of roles in the classroom significantly influences student's intrinsic motivation to learn English (Alharbi, 2015.)

The following potential didactic objectives must be considered when setting up a problem situation: to draw students attention to the course material, spark their curiosity, increase their level of cognitive activity, and expose them to challenges involving intellectual tension, the current knowledge acquired by students, skills and abilities that will arise in the future, it is necessary to show that students' knowledge requirements and it is vital to help analyze educational problems and determine the most rational ways to solve them.

Several types of problem situations in the educational process are distinguished:

- 1. Students do not know how to solve the task, so they cannot answer the problematic question;
- 2. Students are faced with the need to use previously acquired knowledge in a new situation;
- 3. There is a conflict between the way the task can be solved theoretically and the difficulty of applying the chosen method in practice;
- 4. In the performance of the task, there is a conflict between the practical achievement of the result and the student's lack of knowledge to justify it theoretically.

The literature lists the following typical methods for putting oneself in a difficult situation:

- encourage students to explain conflicts and inconsistencies between events and facts;
- encourage them to analyze facts and events that cause a conflict between scientific concepts and life ideas;
- encourage them to draw conclusions and compare facts, events, and actions;
- familiarize them with seemingly incomprehensible facts that caused a scientific problem to be posed in the history of science. Teachers have given students a number of difficult assignments to help them explain the nature of concepts they have studied and events.
- analyze the need for, viability of establishing an authentic communicative environment using communicative language teaching (CLT) to teach speaking, listening using computers, and websites.
- discuss the elements of the learning and teaching model in the authentic communicative environment by using CLT with feedback and evaluation from both the teachers and the students (Canale & Swain, 1980).

## **Materials and Methods**

The main goal of this work is to find if studies of foreign language course in engineering technologies institutions will be more effective when PBL method during the lessons is used. If teachers can successfully do these activities, the students will join thoughts, get into the flow of solving problems, think together, and get excited together, thus becoming participants in the training. By doing this, the teacher directs the student's cognitive process by asking questions, thereby drawing attention to the conflicts in the audience on the studied material and forcing students to think thoughtfully. Before the teacher solves the incomprehensible question, students prepare their answers and compare them with the teacher's opinion and conclusion.

PBL includes the following teaching and learning materials: a) textbooks and novels; b) films and television; c) plays; d) radio programs and podcasts; e) multimedia, applications, software, platforms, and games; f) social media; g) digital learning resources such as video, audio, text, websites, animations, and images, and h) lectures.

PBL learning objectives include the following: students can gain oral skills related to engineering, business, management, and social science, as well as skills related to group work, project management, leadership, self-awareness, and group process evaluation. They can also work independently, critically analyze and explain concepts, engage in selfdirected learning, conduct research, and become information literate (Nilson, 2010).

There are three parts of problems: known (based on the assignment provided), unknown (finding them creates new knowledge), and prior knowledge (students' experiences). They are essential for conducting research to uncover unknown. Students are first given an unknown learning problem to solve; neither the methods nor the outcomes are known. Instead, they must use their prior knowledge and skills to determine the expected outcome or solution.

The 'Problem Situation' method's framework:

• grouping to identify the root causes of a problematic situation;

- considering the ramifications of a problematic situation;
- creating a solution to a problematic situation;
- selecting appropriate solutions.

The 'Problem Situation' method involves the following steps:

the teachers divide the class into small groups, and the groups analyze the given problematic situation to identify the root causes of the issue. The educator selects a problem situation that is relevant to the topic and decides on goals and tasks. The teacher then explains the problem to the students.

- They make opinions about the consequences of the problem;
- they analyze and discuss various approaches to solving the problem to come up with a solution;
- small groups present their suggestions for how to solve the problem situation.

A problem statement of material is fundamentally different from the statement of information, because the signs, properties, concepts, rules of particular phenomenon are simply described, ready conclusions are stated (Brumfit & Johnson, 1979).

One of the widely used methods in the educational process is the method, which is conditionally called the problematic beginning of the statement of educational information. This method differs from the method of problem statement of the material only in that the problem situation is created at the beginning of the statement of the material. Then the material will be presented in an informative way.

The above methods of creating a problematic situation do not limit its other options. Each teacher in his practical activity finds various possibilities of organizing it in the course of creative work with educational materials. The thoughts of the students become more and more complex, the problematic situation creates a certain emotional presence in them, and they are satisfied with the independently realized cognitive process and discoveries.

To facilitate the process of setting the educational problem, it is necessary to follow a certain order. A problem cannot be posed without activating the framework of previously acquired knowledge that is directly related to the new concepts to be solved. Before giving problem tasks, it is necessary to make sure that students have mastered the methods of establishing cause-and-effect relationships, to study the level of ability to analyze a problem situation. It is also possible that the teachers do not bring to the attention problems that are convenient for him. At the same time, it is necessary not to forget that it largely depends on being able to put it correctly.

The teacher should choose a topic based on the interests and experiences of the class so that students become familiar with new words. Students can pick up two or three new words in English. Students can therefore have strong word memory skills. Pupils should be taught to arrange words when they pick up new concepts and vocabulary. The word order in

English is very different. The pupils should fully comprehend it and use it in their speech. To grasp the correct word arrangement, the teacher should encourage speaking among his pupils. He can improve it by posing queries to students and getting their responses. He is capable of setting up talks or debates. Therefore, the student could acquire the habit of speaking.

- The significance of oral work includes the following: It helps students read the text in lessons more effectively and paves the way for textual teaching;
- it makes students perfect in all forms of reading and writing;
- it prevents students from speaking too effectively and from mastering communication skills (Patel & Praveen 2008).

## **Results and Discussion**

As a result of our research, in teaching conditions, the mental and emotional state of a person acts as a special impetus for thinking and intellectual research. The problematic situation arises in specific teaching conditions, which are organized according to the purpose of certain pedagogical tools. The problematic situation is different from any thinking difficulties, in which the student realizes the internal, hidden connections of the object (concept, fact) that required difficulty with the task, a problem known to him (Ashurov, 2016).

Following all conclusions, the same conclusions are summarized under the guidance of the teacher, who chooses the most optimal options for solving the problem situation.

The pedagogue's comprehension of the educational and instructional roles of this education is crucial for planning and carrying out problem-based learning activities. In all phases of the educational process, one can make use of this problem-solving educational technology, for example, in the statement of a new topic, in strengthening and controlling knowledge.

As a result, a task that students are familiar with and can complete on their own cannot be considered an educational problem. Moreover, a task cannot be an educational problem if students are unaware of how to solve it.

The following are significant indicators of a learning disability:

- introducing the unknown, which results in the creation of new knowledge;
- students have a certain knowledge reserve necessary to carry out research to find the unknown.

An important stage of students' mental activity when solving an educational problem to formulate and justify a hypothesis.

The learning problem is consistently developed through problematic questions serving as a step in the solution. The problem components, the character of the relationship between the known and the unknown, create a desire for knowledge and encourage an active search for knowledge. It should be noted that a necessary condition of problem-based teaching is to create a positive attitude towards the process of searching for the truth and its results.

In problem-based learning, students engage in creative and cognitive thinking by expressing problems in the exercise when they arise, that is, they express in words the essence of the occurrence of cognitive difficulties (that is, what is known to them at this moment), and then they look for ways to solve the problem, taking various assumptions. After solving the problem or completing the task, the students take one of the assumptions they find to be true and conduct research to support it. The self-knowledge activity's search phase can be represented by unique schemes: a problematic circumstance an education issue; an investigation into an issue in education; the teacher must have a solid understanding of the training's instructions and instructional functions to plan and lead problem-based training sessions. The instructor should never provide the students with a prefabricated truth (solution); instead, they should inspire them to learn and assist them in mentally processing the data, occasions, and events that are essential to both training and life. The students take as a hypothesis one of the activities.

The purpose of problem-based teaching is to help students effectively master the system of knowledge and the methods of intellectual and practical activities, to create the skills of creative application of knowledge in a new situation, and to solve the problems of learning and education. The problem of practical analysis of the educational process opens up the possibility of determining the uniqueness of teaching. The teacher's unique arrangement of the material for the student to learn is the fundamental component of problem-based learning.

The system of improving educational information is one of the prerequisites for the setup of problem-based learning. The learner's subjective perspective, comprehension of the objectives of knowledge and decision-making, and capacity to assess the available options for problem-solving and outcome-achieving constitute the third prerequisite for problem simulation.

The instructor considers the lesson's goal, the subject matter of the teaching aids, the audience's makeup, the students' preparation level, listening to them, and making connections between them. The high level of educational efficiency can only be guaranteed at that point. It is advised to begin with a problem statement, progressively advance to research work, and progressively advance from simple to complex in the chain of all problem-based teaching techniques in order to engage students in creative activity. It is stressed in pedagogical literature that the development of reproductive and re-development strategies is a prerequisite for implementing students' creative activities (Woods,1996). Therefore, in order for problem-based teaching to be effective enough, it should be an integral part of the educational process. In the process of conducting problem lectures, the formation of motives, valuable guides and referrals necessary for creative activity in students takes an important place. It should be noted that the range of educational activity motives is a sum of many motives, but two groups of them are decisive. Speaking topics can be given in the form of a problem that cannot be solved immediately. In preparation for the workshop activities aimed at revolutionizing the way of thinking, the teacher develops a carefully thought-out scenario that covers the following issues:

- description of students ability to reveal their knowledge sufficient for their participation in problem-solving, as well as the tasks necessary to reveal knowledge;
- getting into the problem and expressing the problem on the basis of bringing out the knowledge of the students;
- formation of the final conclusion (decision)-result of the correct solution of the problem;
- formulating a problem that ensures the complete solution of the problem;
- formation of intermediate conclusions consisting of answers to problems within the problem;
- formulation of problem questions that provide correct answers in solving the issues in the problem.

'Problem situation technology' development of learning language and speaking objectives is a problem-based learning method that aims to develop language and speaking learning goals.

'Speaking' determination of educational goals based on Bloom's taxonomy on the subjects are the following:

Categories of Bloom's taxonomy: learning objectives for speaking topics.

A learner should know: information about speaking processes; knows how to form concepts through oral speech methods.

Must understand: the speaking process-the activities that ensure the creation and implementation of speech; the practice of the humanitarian school understands the development of specific forms and methods of speaking activity and their essence.

The learner should be able to apply: to find ways of forming concepts through oral speech methods, to enrich the form and content of modern teaching in order to stimulate students' motives for learning; effective use of speaking methods in the educational process.

The learner must analyze: the difference between speaking skills processes.

The learner must be able to synthesize: practical application of the created speech, summarizing the ways and stages of achieving high efficiency by further developing it and introducing additions; generalization

of knowledge about the essence of innovative process and methods.

The learner should be able to evaluate: speaking activity, the importance in increasing the effectiveness of the educational process; the importance of speaking methods in increasing student learning rates.

This teaching method can be implemented by switching from the informational-visual approach of reading to a partially creative method, which creates certain cognitive difficulties in students at different stages and conditions which are successfully solved based on the introduction and processing of previously formed knowledge and skills during the teaching process. In the system of preparing students for creative activities, the teacher needs to be able to pay attention to them during the lesson and give appropriate instructions for learning activities. It should also be noted that such an experiment practice aims to confirm the truth of acquired knowledge and ways of seeing thoughtful judgments. Such a course of training forms skills for conducting scientifictheoretical research and experiments, thereby they engage in scientific creativity, and business communication, plan the stages of research, express its goals and tasks (Bloom, 1956).

When asking problematic questions to students, it is necessary to ensure the continuity of problematic questions and their connection with the results of their creative work.

In general, the development of speaking and critical thinking skills include the following stages:

1. bringing to light the knowledge necessary for active participation in creative activities to solve educational problems;

2. getting into the problem and expressing it;

3. organizing problem-solving based on students' previously acquired knowledge;

4. organizing a creative activity on problem-solving (posing a problem and problematic question of finding an answer to a question, expressing intermediate and conclusions).

## Conclusions

- 1. Speaking topics were selected and educational goals were determined in the teaching of this topic, and innovative educational technologies were used.
- 2. Based on the plan drawn up for this topic, educational goals for teaching the topic (according to Bloom's taxonomy) were developed.
- 3. The learner's learning was regularly and effectively monitored, control questions related to the learning material were created.
- 4. As a result of the study of the topic, it was possible more effectively organize the English language lessons using innovative methods, problem-based educational technologies, and problem-based teaching technologies, and reveal the importance of the topic in a broader and deeper sense for students to master.

5. The methodology of teaching this subject has been developed when the training is conducted using the above methods, the level of mastery of the subject

increases, the efficiency of the lesson increases, and the training is conducted in an unconventional and demonstrative way.

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## THE USE OF ARTIFICIAL INTELLIGENCE BY STUDENTS OF INFORMATION TECHNOLOGY PROGRAMMES

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## Abstract

The use of artificial intelligence (AI) tools in university education is a phenomenon of various directions: the potential of AI tools, skills, purpose and sense of usage. Each direction is worth of working out and introducing regulatory systems and deeper investigating users' choice and managing the process of getting, navigating and creating information by means of AI. Therefore, one of the emerging scientific challenges is students' abilities and personalised learning experience in the use of AI. The study is focused on the usage of AI in specific courses, and namely the students of Information Technology (IT) programmes from Latvia University of Life Sciences and Technologies (LBTU) and Riga Technical University (RTU). The aim of the study is to investigate the students' ability, need and merit to use AI in learning numerical methods, mathematics and programming. The main data collection method used is a student survey. According to the main results, it is found out that respondents when solving the programming tasks sometimes used AI, while solving mathematical tasks respondents rarely used AI. AI actually did not help to solve the mathematical tasks, while it partly helped to solve the programming tasks. The use of AI partly helped the respondents to improve the knowledge and skills of programming. Acquiring the study course Numerical Methods respondents mainly used ChatGPT, but performing practical works respondents mostly did not use AI.

Key words: artificial intelligence (AI), university, IT students, numerical methods, mathematics, programming.

## Introduction

Nowadays artificial intelligence (AI) is a dynamically developing concept and it contains multi-sided usage from the point of view of its opportunities. Therefore, it is necessary to explain how, what for and why the definite AI is used.

The increasing usage of AI and its scope and potential is explicitly topical but this process keeps also high necessity of developing new learning skills and regulatory systems. UNESCO has published several documents on AI usage particularly in education because the access to AI and appropriate policy making is becoming an essential challenge to students and governing authorities (UNESCO, 2023a). UNESCO claims educational institutions 'to validate GenAI systems on their ethical and pedagogical appropriateness for education' (UNESCO, 2023b). Therefore, common understanding of AI is crucial in the development of further policy and solutions, and UNESCO defines that 'Generative AI (GenAI) is an (AI) artificial intelligence technology that automatically generates content in response to prompts written in natural - language conversational interfaces' (UNESCO, 2023b).

However, Organisation for Economic Co-operation and Development (OECD) defines that 'Artificial intelligence system: a machine-based system that, for explicit or implicit objectives, infers, from the input it receives, how to generate outputs such as predictions, content, recommendations or decisions that can influence physical or virtual environments. Different AI systems vary in their levels of autonomy and adaptiveness after deployment' (OECD. AI Policy Observatory, 2023).

The usage of AI causes numerous challenges as 'fragmentation, vague definitions, guardrail ambiguity and model access', and there is analysis what 'safe generative AI models' mean in the frame of 'current AI landscape' (AI Governance Alliance, 2024).

By OECD, AI is considered from five crucial valuedbased principles. In the rationale of the inclusive growth, sustainable development and well-being the principle of supportive and AI promoting attitude is emphasized in relation to 'social good' and 'to achieving the Sustainable Development Goals (SDGs) in areas such as education, health, transport, agriculture, environment, and sustainable cities, among others' (OECD. AI Policy Observatory, 2023).

The use of AI in university learning environments is developing depending on the nature of assignments and obtained course. Students try to use AI creatively to reach better learning results. This process should be promoted also in the interaction with teachers and tutors helping to comprehend and improve smart, transparent, safe and ethical usage of AI.

The scope of scientific problems in the field of AI research is wide covering privacy, fairness, critical thinking, academic integrity, quality and reliability of AI generated content, access of AI, mental health, personalised experience, ethics, teaching and research quality, adaptation to AI, and changes in teaching/learning process issues. That is why the particular investigation on the usage of AI in students' learning is focused on their personal experiences and has been carried out at Latvia University of Life Sciences and Technologies (LBTU) and Riga Technical University (RTU), and it outlines the problems and successes of the process.

The aim of the study is to investigate the students' ability, need and merit to use AI in learning numerical methods, mathematics and programming.

## Materials and Methods

The study has been carried out during the autumn semester of 2023 by means of the survey, and 187 students of Information Technology programmes from LBTU and RTU participated. The total number of students who were approached to participate in the survey is around 500, consequently, 37% of students expressed their opinion.

Both higher education institutions have similar background because there are IT programmes and students study the courses of numerical methods, mathematics and programming. This background is chosen also for the reason that all three courses are interconnected and mutually complementing each other. Numerical methods are mathematical methods used to solve problems in various disciplines that use mathematical models. These involve numerical solutions using computational algorithms through computer programming. implemented Students study this course when they have already completed the higher mathematics course and acquired programming skills and abilities.

138 students (74% of the surveyed students) stated that they have used AI tools in the learning process. Therefore, the answers given by these students will be further analysed. Results from nine questions of the survey were used in the study. This group of questions focused on getting information about reasons, merit and frequency of the usage of AI in the study courses of numerical methods, mathematics and programming. Respondents for the study were randomly selected. The online survey took place under the same conditions. The number of questions asked is relatively small, so the probability of the effect of fatigue is small. The survey data is qualitative, so nonparametric statistics, in this case the chi-square test, were used to process the data (Gunarto, 2019).

The frequency of respondent answers (for all questions) was statistically analysed using chi-square test (Tables 1-9). The following hypotheses were tested for further data analysis:

H<sub>0</sub>: the frequency of the answers is the same;

 $H_1$ : the frequency of respondent answers differs significantly.

The data were analysed statistically by using SPSS software.

#### **Results and Discussion**

Two survey questions were about using of AI tools to solve either a mathematical or programming task ('How often do you use AI tools to solve a mathematical or programming task?')

'Figure 1' shows that for solving the programming tasks respondents sometimes used AI (57 or 41%), while for solving the mathematical tasks respondents rarely used AI (58 or 42%). AI is able to write a code, optimize the existing code or to point to possible problems. This is why respondents used AI in the tasks of programming.





The frequency of respondents' answers about the use of AI tools for solving both mathematical and programming task was statistically analysed in Table 1 and 2.

Table 1 Chi-square test statistics of frequency of AI tools usage to solve a mathematical task

0	Observed	Expected	Residual
	Ν	Ν	
Often	11	34.5	-23.5
Sometimes	37	34.5	2.5
Rarely	58	34.5	23.5
Never	32	34.5	-2.5
Total	138		
Chi-Square		32.377	
df		3	
Asymp.Sig.		0.000	

Since the p-value of 0.000 is below the significance level of  $\alpha = 0.05$ , we can reject the null hypothesis. Therefore, it can be concluded that there are differences in the frequency of respondents' answers and the answer 'Rarely' being statistically significant. According to the authors' experience, in mathematics courses, students most often use AI tools to understand how to complete a task step-by-step. At the same time, students note that when trying to solve problems from different mathematics courses, a different and not always correct solution is offered every time, so AI tools are rarely used for solving mathematical problems.

Table 2

Chi-square test statistics of frequency of AI tools usage to solve a programming task

		<u> </u>	
	Observed	Expected	Residual
	Ν	Ν	
Often	38	34.5	3.5
Sometimes	57	34.5	22.5
Rarely	37	34.5	2.5
Never	6	34.5	-28.5
Total	138		
Chi-Square		38.754	
df		3	
Asymp.Sig.		0.000	

Since the p-value = 0.000 is less than the significance level of  $\alpha$  = 0.05, the null hypothesis can be rejected. Thus, it can be concluded that the frequency of respondent answers is different. Statistically significant prevalence was observed in the answer 'Sometimes'. According to the authors' experience, students most often use AI tools to quickly identify errors in programming code, optimize it, and understand how operators function.

Two other survey questions focused on whether AI helped to solve a mathematical or programming task ('Did AI help with mathematical or programming task?') 'Figure 2' illustrates that AI actually did not help in solving mathematical tasks (48 or 35%), while it partly helped to solve programming tasks of (56 or 41%). This can be explained as AI can provide answers in the most popular languages of programming and help with scripts, but mathematical tasks are unique.



■ Mathematics ■ Programming

Figure 2. AI helped to solve a mathematical or programming task (N=138).

The answers to mathematical (Table 3) and programming (Table 4) tasks were analysed separately using Chi-square test below.

I able 1	)
Chi-square test statistics for whether AI helped	
solve a mathematical task	

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solve a mathematical task			
	Observed	Expected	Residual
	Ν	Ν	
Helps completely	4	27.6	-23.6
Partly helps	14	27.6	-13.6
Difficult to say	30	27.6	2.4
Partly does not help	48	27.6	20.4
Absolutely does not help	42	27.6	14.4
Total	138		
Chi-Square		49.681	
df		4	
Asymp.Sig.		0.000	

Since the p-value of 0.000 is below the significance level of  $\alpha = 0.05$ , we can reject the null hypothesis. Therefore, it can be concluded that there are differences in the frequency of respondents' answers

and the answer 'Partly not helps' being statistically significant.

Table 4

Chi-square test statistics for whether AI helped solve a programming task

	Observed	Expected	Residual
	Ν	Ν	
Helps	20	27.6	1.4
completely	29	27.0	1.4
Partly helps	56	27.6	28.4
Difficult to say	27	27.6	-0.6
Partly does not	20	27.6	76
help	20	27.0	-7.0
Absolutely	C	27.6	21.6
does not help	0	27.0	-21.0
Total	138		
Chi-Square		48.304	
df		4	
Asymp.Sig.		0.000	

Since the p-value of 0.000 is below the significance level of  $\alpha = 0.05$ , we can reject the null hypothesis. Therefore, it can be concluded that there are differences in the frequency of respondents' answers and the answer 'Partly helps' being statistically significant.

Two other survey questions focused on improving mathematical or programming knowledge and skills using AI ('Does using AI help you improve your programming knowledge and skills?')

<sup>•</sup>Figure 3<sup>°</sup> shows that respondents had difficulty judging whether AI helped to improve mathematical knowledge and skills (39 or 28%), while using AI partly helped respondents to improve the programming knowledge and skills (59 or 43%).





Figure 3. Improving mathematical or programming knowledge and skills using AI (N=138).

The answers to mathematical (Table 5) and programming (Table 6) tasks were analysed separately using Chi-square test below.

Since the p-value of 0.000 is below the significance level of  $\alpha = 0.05$ , we can reject the null hypothesis. Therefore, it can be concluded that there are differences in the frequency of respondents' answers and the answer 'Difficult to say' being statistically significant.

	Observed N	Expected N	Residual
Absolutely not helps	25	27.6	-2.6
Partly not helps	31	27.6	3.4
Difficult to say	39	27.6	11.4
Partly helps	36	27.6	8.4
Helps completely	7	27.6	-20.6
Total	138		
Chi-Square		23.304	
df		4	
Asymp.Sig.		0.000	

Chi-square test statistics about improving mathematical knowledge and skills using AI

Table 5

This response was expected because there are students who admit that they use AI tools to explain a mathematical problem-solving algorithm, while several students believe that an AI tool often gives the wrong solution to a mathematical problem.

	Table 6
Chi-square test statistics about improv	ing
programming knowledge and skills usin	g AI

<u> </u>	mienieage		
	Observed	Expected	Residual
	N	N	
Absolutely not	4	27.6	22.6
helps	4	27.0	-23.0
Partly not helps	7	27.6	-20.6
Difficult to say	16	27.6	-11.6
Partly helps	59	27.6	31.4
Helps	50	27.6	24.4
completely	52	27.0	24.4
Total	138		
Chi-Square		97.725	
df		4	
Asymp.Sig.		0.000	

Since the p-value of 0.000 is below the significance level of  $\alpha = 0.05$ , we can reject the null hypothesis. Therefore, it can be concluded that there are differences in the frequency of respondents' answers and the answer 'Partly helps' being statistically significant. This response was expected, because many students admit using AI tools to understand how programming code works and find errors in their own.



Figure 4. Using AI in course 'Numerical Methods' (N=135).

One survey question was about using AI in the course 'Numerical Methods' ('Did you use AI in the course Numerical Methods?').

'Figure 4' shows that respondents mostly did not use AI acquiring the study course 'Numerical Methods' (108 or 80%).

The frequency of respondent answers (using AI in the course 'Numerical Methods') was statistically analysed in Table 7.

Table 7

Chi-square test statistics of AI tools used in the course 'Numerical Methods'

	Observed N	Expected N	Residual
Yes, I use	27	67.5	-40.5
No, I don't use	108	67.5	40.5
Total	135		
Chi-Square		48.6	
df		1	
Asymp.Sig.		0.000	

Since the p-value of 0.000 is below the significance level of  $\alpha = 0.05$ , we can reject the null hypothesis. Therefore, it can be concluded that there are differences in the frequency of respondents' answers, and the answer 'No, I don't use' is statistically significant. Several students indicated that they were provided with good learning materials and therefore they did not need to use AI tools.

One survey question was about the usage of AI for practical works in the course 'Numerical Methods' ('Could you use AI for all practical works in the Numerical Methods course?'). This question was asked because the authors and their colleagues have verified that in some cases the correct answer is obtained by AI, and AI can help with practical tasks.

'Figure 5' shows that respondents acquiring the study course 'Numerical Methods' and performing practical tasks mostly did not use AI (120 or 94%).



Figure 5. Usage of AI for all practical tasks in course 'Numerical Methods' (N=128).

The frequency of respondents' answers (using AI for all practical works in the course 'Numerical Methods') was statistically analysed in Table 8.

Table 0

			Table 8
Chi-square test	statistics of	AI tools us	ed for all
practical wo	rks in the co	ourse 'Num	erical
-	Methods	5'	

	Observed N	Expected N	Residual
Yes, I use	8	64.0	-56.0
No, I don't use	120	64.0	56.0
Total	128		
Chi-Square		98.000	
Df		1	
Asymp.Sig.		0.000	

Since the p-value of 0.000 is below the significance level of  $\alpha = 0.05$ , we can reject the null hypothesis. Therefore, it can be concluded that there are differences in the frequency of respondents' answers, and the answer 'No, I don't use' is statistically significant. Only a few students tried to use the AI tools in every practical task, but the students themselves admit that this was because they wanted to challenge themselves and the AI tool and still get the right answer by asking the questions correctly in multiple attempts.

One of the survey questions was about the use of different AI tools in the course 'Numerical Methods' ('Which AI tool did you use for the course Numerical Methods?'). 'Figure 6' shows that respondents mostly used ChatGPT acquiring the study course 'Numerical Methods' (35 or 41%), or did not use AI at all because it does not help (33 or 39%). The other AI tools were used very little – Microsoft Bing was used by 14 or 16% respondents, Google Bard was used only by 3 or 4% respondents.



Figure 6. Usage of different AI tools in the course 'Numerical Methods' (N=85).

The frequency of respondents' answers (use of different AI tools in course 'Numerical Methods') was statistically analysed in Table 9.

Since the p-value of 0.000 is below the significance level of  $\alpha = 0.05$ , we can reject the null hypothesis and conclude that the frequency of respondent answers is different. Statistically significant prevalence was the answer ChatGPT.

Tuble	′
Chi-square test statistics of different AI tools used	l
in the course 'Numerical Methods'	

	Observed	Expected	Residual	
	Ν	Ν		
ChatGPT	34	17.0	17.0	
Bing	14	17.0	-3.0	
Chat	1	17.0	-16.0	
Google Bard	3	17.0	-14.0	
Other	33	17.0	16	
Total	85			
Chi-Square	59.176			
df	4			
Asymp.Sig.	0.000			

The use of AI in learning process is in line with the choice of AI-generated content assessing it critically and using appropriately in a particular context. Students have to assess their needs, merit and challenges including capabilities and limitations using AI. There is a risk of limited or even incorrect information. Hence, understanding the necessity of meeting the needs of critical thinking, continuous development of skills of using AI and adapting to it should be an essential part of students' learning. Of course, AI offers great opportunities to learn, find and choose information, but it is a challenge as well. In this situation, educational institutions also have to adapt and offer integrated themes or courses to promote successful usage of AI for students and academic staff as well. That is why both investigations related to students and academics in the use of AI are vitally important.

So, the impact of Chat GPT and AI has been analysed among academics as well covering the questions about integration of Chat GPT in research and educational work, ethical aspects and its impact on future work (Livberber & Süheyla, 2023).

Students' interest and involvement in learning process also vitally depends on academics' 'attitude to emerging technologies' (McGrath *et al.*, 2023), and the use of AI is not an exception. It means that the academics have to change a lot in their practices by means of adapting to rapidly changing AI progress and developing new teaching and mutual co-operation methods to help the students.

LBTU and RTU students' interest on learning and using AI was mainly in the programming tasks and mostly by ChatGPT. It is worth mentioning that in the study by Manuela-Andreea Petrescu, Emilia-Loredana Pop and Tudor-Dan Mihoc about the second year Computer Science students at Babes-Bolyai University in Romania the data on students' interest in learning AI were quite different, and, for example, applicability and innovative aspects of AI were more scored by men than by women (Petrescu, Pop, & Mihoc, 2023).

The study from Hong Kong on a survey results of '399 undergraduate and postgraduate students from various disciplines' reflects the students positive attitude towards GenAI both in their teaching and learning process, and 'the potential for personalized learning support, writing and brainstorming assistance, and research and analysis capabilities. However, concerns about accuracy, privacy, ethical issues, and the impact on personal development, career prospects, and societal values were also expressed' (Chan & Hu, 2023).

Research at the graduate level has to be increased because of growing AI opportunities and also in the aspects of its advancement (Crompton & Burke, 2023).

The study is devoted to personalised student experience, and contribution of AI could be substantial in personalised learning process. Speaking about the evolution of AI, J. Neill stresses the opportunities to create personalised study plans, adapting to students' learning styles and strengths as well as standardized test preparation (Neill, 2023).

The opportunities of AI are also essential in career development because of offered 'writing tools, subject and career exploration, college selection, resume enhancement, interview preparation, portfolio development and evaluation and study guides or customised test preparation' (Neill, 2023). Students who are serious about their career development should be interested in acquiring AI tools and this direction should be enhanced by academic staff as well to help the students to find out the most appropriate occupation in a wide and multisided field of IT.

There is also an example in the form of a guide providing systemic and practical instructions for teaching AI and particularly ChatGPT (Center for the Advancement of Teaching, 2023).

As the use of ChatGPT has essentially grown in the world, a special attention should be devoted to the potential of this tool (Fütterer *et al.*, 2023). The anonymous survey results from more than 6300 students in Germany show 'that almost two-thirds of the students surveyed use or have used AI-based tools as part of their studies. In this context, almost half of the students explicitly mention ChatGPT or GPT-4 as a tool they use. Students of engineering sciences, mathematics and natural sciences use AI-based tools most frequently' (Von Garrel & Mayer, 2023). The survey results from LBTU and RTU also confirm that the tool of ChatGPT is the most popular among IT students.

Kevin Dykema, President of National Council of Teachers of Mathematics, emphasizes that AI could be an essential aid both for students and teachers but it will not replace them, and constant learning about its usage in mathematics is important because integration of AI in teaching/learning process is an indicator of following the development of nowadays technologies (Dykema, 2023). Therefore, more adaptive learning and personalized learning experiences could be developed through AI systems (Sinha, 2023).

The study data from LBTU and RTU is an evidence of problems students meet, and highlights that specific knowledge and skills of the use of AI should be improved by the students themselves and/or by the assistance of academic staff because AI actually is an aid giving a unique opportunity to achieve higher learning outcomes also in quite complicated exact courses.

## Conclusions

- 1. AI has transformational impact on higher education processes and student/academic staff's ability to adapt, assess and use it appropriately and redesign practice to make teaching/learning more effective.
- 2. Continuous learning and necessity to organise also further education courses or themes integrated in regular courses to be in line with the development of AI is a new challenge for higher education institutions.
- 3. The use of AI by IT students can impact their personalised learning process and career development, but it is significantly related to their conscience and understanding of AI opportunities.
- 4. A gap between AI opportunities, the usage skill and ethical and legislation aspects is an indicator of nowadays challenges on the country and institutional level. It means that the development of AI literacy and skills is a complex work depending on willingness to be in line with the progress of knowledge society.
- 5. With a probability of 95%, it can be concluded that solving the programming tasks, respondents sometimes used AI (p-value = 0.000), while solving the mathematical tasks, respondents rarely used AI (p-value = 0.000). AI actually did not help to solve the mathematical tasks of (p-value = 0.000), while it partly helped to solve the programming tasks (p-value = 0.000). The use of AI helped respondents to partly improve the knowledge and programming skills (p-value = 0.000).
- 6. When acquiring the study course 'Numerical Methods' respondents mainly used ChatGPT (p-value = 0.000), while performing practical tasks, respondents mostly did not use AI (p-value = 0.000), because it does not help and students are mostly satisfied with the materials offered by the lecturer within the study course.

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# THE NEED AND ROLE OF HIGH-LEVEL MATH SKILLS IN ENGINEERING STUDIES

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## Abstract

This article examines the importance and necessity of high-level mathematical skills in engineering studies. It analyzes the specific mathematical skills required for successful engineering education and their role in engineering studies. The results provide insight into how high-level mathematical skills contribute to the development of engineering competencies and enable engineers to solve complex problem scenarios. Key findings reveal that high-level mathematical skills are indispensable in engineering education, providing the tools needed to solve real-world problems and drive innovation in engineering. Mathematics is the language of engineering. It provides the analytical and problem-solving tools necessary for engineers to design, analyse, and optimize systems, ensuring that they meet safety, efficiency, and performance requirements. Engineers use math as a fundamental tool to make informed decisions and drive technological advancements across various engineering disciplines. Without math, engineering would be severely limited in its ability to design safe, efficient, and innovative solutions to the complex problems that engineers encounter in various industries. The questions contained in the article are investigated using survey data of university students. The purpose of this study is to research the relative applicability and level of knowledge of the learning material learned in secondary educational institutions in mathematics, based on the experience of school graduates and engineering students.

Key words: mathematical skills, role of mathematics, engineering studies.

## Introduction

The world is constantly undergoing various changes in economy, politics, and education. There are many different educational systems, which are evaluated ambiguously by experts.

There are also continuous reforms and changes in Latvian education, about the structure of which, implementation rates and role in the growth of young people, there are continuous discussions, up to protests. One of the most widely discussed blocks of learning subjects is exact sciences, their necessity, quality and intensity of teaching (from various aspects) (Kopeika & Zvirgzdina, 2020).

In order to understand the situation more fully and at least to try to find solutions to the problems that have arisen or are already lasting, it is not enough to evaluate it only from the position of experts (both local and international).

It is also worth listening to the judgments of educators and, even more, to the opinions of young people themselves.

Regarding the new policy of the education system in the field of exact subjects (especially mathematics), experts and teaching forces have grouped themselves into two groups with radically opposite attitudes towards what is happening.

The authors of the article do not join any of these groups, because each of the systems, both old and new, have both positive and negative trends.

Mathematics studies have an impact on the development of the necessary outcomes for engineers' both directly and indirectly (Harris *et al.*, 2015; Zeidmane & Rubina, 2017).

Mathematics plays a crucial role in engineering, serving as the foundation upon which engineers build and apply their knowledge to solve real-world problems, see 'Figure 1'.



Figure 1. Mathematics a crucial role in engineering studies.

Here are some key ways in which mathematics is indispensable in engineering (Tunesk, 2022; Saranya, 2023):

- *Problem Solving:* Engineers often face professional problems that require logical thinking and problem-solving skills. Mathematics provides the foundation for developing these skills and enables engineers to break down complex problems into smaller, manageable components.
- *Modeling and Analysis:* Engineers must use mathematical models to represent a real-world system. Mathematics helps engineers analyze these models, predict outcomes, and make informed decisions.
- *Precision and Accuracy:* Undoubtedly, engineering requires a very high level of precision. Mathematical tools such as calculus, algebra, and statistics allow engineers to make accurate calculations and

measurements, reducing the risk of errors in design and analysis.

- *Optimization:* Engineers often need to optimize systems and processes to achieve specific goals, such as reducing costs, increasing efficiency, or optimizing performance.
- *Design and Innovation:* Mathematical principles underlie the design of various engineering systems and technologies. Whether it's a bridge, an airplane, or a computer chip, engineers rely on mathematical principles to ensure that their design is functional, safe, and efficient.
- *Data Analysis:* In the age of data-driven decisionmaking, engineers must analyze large sets of data to improve processes and products. Statistics and data analysis techniques are essential for drawing meaningful conclusions from data and making informed decisions.
- *Electrical and Electronics Engineering:* Engineers working in fields like electrical and electronics engineering rely heavily on mathematical concepts, such as complex numbers and differential equations, to design circuits, analyze signals, and develop electronic systems.
- *Control Systems:* Control systems engineering involves designing systems that regulate and control processes. Mathematics, particularly differential equations, and linear algebra, is essential for modeling, analyzing, and designing control systems.
- *Materials Science and Mechanics:* Engineers in fields like materials science and mechanics use mathematical concepts to understand the behavior of materials under different conditions, predict mechanical properties, and design structures that can withstand various loads.
- *Innovation and Research:* Engineers involved in research and development often need advanced mathematical tools and techniques to push the boundaries of technology and innovation.

More than half of practising engineers use a high level of curriculum mathematics in their work. There is also evidence that engineers' mathematical thinking usage is significantly greater than their curriculum mathematics usage (Goold & Devitt, 2012).

Without mathematics, engineering is impossible, and the consequences in this field would be significant (Saranya, 2023), see 'Figure 2':

- 1) *Lack of precision:* Without mathematics, engineers would have to rely on trial and error, intuition, or imprecise methods that could lead to less accurate designs and potentially dangerous results.
- 2) *Inefficient designs:* Without mathematics, engineers would struggle to find the best solutions among many possible alternatives, resulting in less efficient designs.
- Safety Concerns: Math plays a crucial role in ensuring the safety of engineering projects. Without math, engineers would have a much harder time assessing safety risks and ensuring that projects meet safety standards.



Figure 2. Impact of lack of mathematics in engineering.

- 4) *Limited innovations:* Many innovative developments in engineering are driven by mathematical concepts and techniques. Without mathematics, the pace of innovation in engineering is likely to slow significantly.
- 5) *Infeasibility of Complex Projects:* Many engineering projects, such as designing modern aircraft, bridges, or computer chips, rely heavily on advanced mathematical principles. Without math, these complex projects would be practically impossible to undertake.
- 6) Data Analysis Challenges: In today's data-driven world, engineers need mathematical tools to analyze large sets of data and make informed decisions. Without math, engineers would struggle to draw meaningful conclusions from data, hindering their ability to improve processes and products.
- Control Systems Issues: Without math, engineers would struggle to design effective control systems, leading to inefficiencies and instability in processes.
- 8) *Materials and Mechanics Challenges:* Without math, engineers would struggle to predict how materials will perform and design safe and reliable structures.
- 9) Limited Career Opportunities: Engineering is a highly technical field that requires strong mathematical skills. Without math, individuals would find it challenging to pursue careers in engineering, limiting the pool of talent available to solve complex engineering challenges.

## **Materials and Methods**

This article analyzes the assessment of the learning process and content of engineering students (1st to 4th year) in mathematics. 260 students from Riga Technical University (RTU) and Latvia University of Life Sciences and Technologies (LBTU) participated as respondents. Students are currently pursuing programs in smart electronics, telecommunications engineering, automotive electronics, agricultural engineering, and machine design and manufacturing. The results of the survey were analyzed with descriptive statistics, the general scientific logically constructive and graphic method was applied.

## **Results and Discussion**

Although 80% are RTU students, taking into account the number of students in both universities, such a difference is acceptable. Before starting their studies, the respondents have obtained secondary education in schools of different profiles (see Table 1).

Table 1

Obtained secondary education of respondents								
RTU Engineering Secondary School	Private school	Professional technical school	State Gymnasium	Secondary School				
2%	1%	18%	23%	55%				

Obtained secondary advection of respondents

It must be recognized that only 48% of these young people have also passed the higher level centralized exam in mathematics after graduating from university in 2023. When evaluating what level of exam the young people took and comparing the results, only the results from the 1st year students are taken into account, which is almost 40% of all the respondents, so the results can be considered significant. Comparing the results obtained by students in two exams, a pronounced regularity can be seen. If you compare the results, group the 10% interval in this Highest rating, both ratings are equivalent, except for the group 1% to 100%, clearly better results in the group have been achieved in the highest level exam. It is better if you evaluate the exact results, as there is only a small part of all respondents, or 7%, for whom the results of the Optimal exam are rated higher.

There are several explanations for this situation. It would seem that the most important factor is that a large number of students, at least until now, have taken both these exams by the end of the 12th grade, which is exactly one year after the optimal level of study of the exam topics at school.

However, several other factors are even more important - the number of mathematics lessons at school, the amount of topics to be learned, the pace of teaching, the interest of students and others.

We all know that the number of mathematics lessons per week at school depends on the chosen program, sometimes also depending on the attitude of the school or the municipality. So from 2 hours per week, for example, in the Riga Trade vocational secondary school, moreover, probably due to the lack of teachers, they take place in modules way, to 8 hours per week, for example, RTU Engineering Secondary School, where there are 4 math lessons and 4 math groups per week. There are schools in Latvia that provide even 12 hours a week, but no permission was received to publish information about them. It seems logical, the student is not good at the exact subjects, so he chooses the program with the least number of hours. But a dilemma arises, the optimal level exam must be taken by all young people at the same level, the program must be equivalent.

There are more and more young people for whom it is very difficult to understand and remember mathematical relationships, and sometimes it seems impossible (this is a global problem). The authors of the article will not investigate the reasons for this situation. In order to understand and be able to see mathematical relationships, to be able, at least at an intermediate level, to solve problems of a mathematical nature, it is necessary to devote much more time to intensive studies, in cooperation with a teacher. Homework must also be done regularly, without which successful learning of topics is unthinkable.

Table 2

Obtained secondary education	Yes	No
RTU Engineering Secondary School	100%	0%
Private school	100%	0%
Professional technical school	18%	82%
State Gymnasium	91%	9%
Secondary School	17%	83%

Students'	answers to the o	mestion	<b>'Was the number</b>	of lessons in	n mathematics	sufficient at school'
Students		Jucsuon	was the number	OI ICSSUIIS III	i mauntmants	Summent at Senoor

The previous information is confirmed by the data presented in Table 2. In addition, many young people, indicating that the number of lessons in this subject was sufficient for them, indicate several comments and remarks:

- it was enough for me, because mathematics is my favourite subject, but it was too little for a large part of my classmates;
- it was enough because I also studied with a private teacher;

• I personally would like more because I like mathematics.

It should not be forgotten that engineering students participate in the survey, young people, a large part of whom understand the necessary basic relationships in mathematics, diligently and actively listen and solve in classes and at home, go to consultations in case of confusion and do not comment on each new topic 'Where will this be useful for me in real life'.

Changes in the topics to be learned at school course are also not insignificant.

Widely available resources do not provide sufficient information on the extent to which mathematical skills

learned during school are used in later studies. It is clear that for this amount of information, the number of contact hours in schools is catastrophically small, especially when learning the optimal block of mathematical knowledge.

In the research, an assessment of young and future engineers has been carried out - how intensively they use what they learned at school during their studies, both in study subjects and also when developing coursework, projects and research papers.

The research included questions about topics to be learned in the optimal mathematics program, see 'Figure 3'.



Figure 3. Respondents' answers to the question: 'To what extent do you use the mathematics topics learned in high school in your studies to understand and evaluate different engineering situations?'

From the answers, it is clear that more than 80% of students admit that they use all topics learned at school very often, often or occasionally.

With the exception of spatial bodies, straight in the plane probability theory, combinatorics and statistics, which are considered widely applicable in studies by 53% to 58% of respondents, which is also not a small number.

Taking into account the results obtained both from the survey and from work experience in cooperation with students, it should be emphasized that students in engineering sciences especially need knowledge of exponential functions and power properties, logarithms, graphs of functions and trigonometry.

Respondents, both those who acquired this knowledge sufficiently well at school, and those who diligently studied the optional subject 'Elementary Mathematics' (32 academic hours) in the 1st semester of study and during which they repeated or learned the indicated topics (the majority of such respondents were, i.e. 85% of respondents) indicated that this knowledge not only helps to understand the topics learned in professional study courses much easier, but also creates an understanding of how these relationships are formed and why exactly they are. Of course, this is possible if you also study regularly and intensively at university and add skills in higher mathematics to your high school knowledge.

Unfortunately, we have to admit that the school program for learning these topics has not only reduced the number of contact hours, but also the number of topics included in the program has been reduced to a minimum.

The authors agree that study blocks of math topics such as trigonometry, operations with roots, graphing functions, and more are difficult. But does this make the need for knowledge less, and just a short overview of these topics is sufficient?

Arriving at the university, it is very difficult for a large number of students to start successful studies precisely because of the lack of this knowledge.

The authors understand that artificial intelligence is increasingly entering our everyday life, research and performance of various tasks.

Solutions to many different problems can be found with the help of computer equipment. We cannot forget that the most advanced and promising is the education of competences. It should not be forgotten that competence education is the next level of development, because without knowledge there will be no competence. In order to base research on electronically developed research results, one must understand their operating principles, be able to evaluate them objectively, and only then professionally interpret the obtained results.

Although significant differences were observed between the answers of the students of the two universities, these results will not be analyzed in this study, taking into account the significant numerical superiority of RTU students in the survey.

## Conclusions

- 1. Mathematics serves as the foundation upon which engineering principles are developed and applied.
- 2. High-level math skills form the foundation of engineering studies, empowering engineers to

conceptualize, analyze, and innovate in a variety of fields.

- 3. As engineering continues to evolve, the need for mathematical knowledge in the field remains paramount in driving progress and innovation forward.
- 4. Recommendations to the persons from the State Educational Content Center responsible for the mathematics learning program in schools is to find an opportunity to schedule more contact hours for learning the basic mathematics course.
- 5. Recommendations for municipalities and school management is to organize optional classes, during which opportunities for solving various practical tasks, using the material to be learned in mathematics, would be organized for students who find it difficult to learn this subject.
- 6. Although the audience of the research is only engineering students and future specialists, the trend was clearly marked that topics such as exponent functions, logarithms, graphs and properties of various functions, but especially trigonometry, are taught too little in secondary educational institutions.
- 7. It should not be forgotten that competence-based education will be effective only if it is based on fundamental knowledge.
- 8. This study is a case study and it only reflects the views of the respondents who participated in it. The results could be used to identify problems/ directions for in-depth research.

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