COMBUSTION ABILITY OF ENERGY CROP PELLETS

Rasma Platače, **Aleksandrs Adamovičs**
Latvia University of Agriculture
e-mail: rasmins@inbox.lv; Aleksandrs.Adamovics@llu.lv

Abstract
Future perspective of the research is the production of fuel pellets from energy plant (*Phalaris arundinacea* L., *Festuca arundinacea*, etc.) biomass, because it can be better burnt in granule burners and is more environmentally friendly, if compared to the fossil mineral resources (coal, oil, gas), moreover it has low moisture content (70 – 90 g kg^{-1}) and correspondingly it produces higher combustion energy. The research covered preparation of various content tablets from reed canary grass *(Phalaris arundinacea* L.*)* variety 'Marathon' (N fertilizer rate on the N-90 kg ha^{-1}), energy wood - osier *(Salix viminalis* L) and poplar (*Populus tremula* L.) with N fertilizer norms N-0 and N-120 kg ha^{-1}, and afterwards research of the combustion ability of and ash content in these tablets. Combustion ability of reed canary grass (*Phalaris arundinacea* L.) variety 'Marathon' reached 17.48 MJ kg^{-1}. The highest average combustion ability with different pellet content was found for the fast-growing poplar both with doses of N fertilizer - 18.55 MJ kg^{-1} and without N fertilizer - 18.49 MJ kg^{-1}. Optimum content of various component pellets for biomass was a mixture of components 1/3 (reed canary grass/osier or poplar). The lowest indicators in respect to the ash content were observed for osier (*Salix viminalis* L.) - 27.9 g kg^{-1}. The best ash content indicators for a mixture of granular composition was in a mixture of components one-fourth of the reed canary grass with three parts of osier - 34.3 g kg^{-1} or with poplar - 41.8 g kg^{-1}.
Key words: *Phalaris arundinacea* L., *Salix viminalis* L., *Populus tremula* L., ash content, combustion ability, nitrogen fertilizer.

Introduction

Along with the accession of the European Union countries to the Kyoto Protocol, which aims at restriction or even complete refusal from the fossil fuels, renewable energy resources should be reasonably used, amount of greenhouse gas emissions should be reduced, and, at the same time, environmentally friendly energy production from renewable energy sources should be enhanced (Enerģētisko …, 2007).

On a global scale, resulting from the reduction of fossil raw materials the need for renewable energy resources is growing. Although production of energy from forestry products is traditional, increase in the fossil energy prices has led also to the beneficial production of energy from agricultural produce – biomass (DIRECTIVE ..., 2009).

An overall negative trend for production of fuel pellets in Europe, including the Baltic States, that should be considered is the lack of traditional raw materials (saw-dust from conifers), obtained from the wood processing industry waste (Adamovičs et al., 2009).

Studies on this subject are topical, especially the ones devoted to search of alternative biofuel raw material sources, as well as discussed in the global forums in respect to the problems of biomass use for energy needs.

Currently, biomass use comprises approximately 14% of the total global balance of energy resources (50 EJ per year from the total 406 EJ per year). For the last 15 years, heat and power generation from biomass in the EU countries has increased by 2 – 9% per year, though it gives only about 5% of the total amount of energy produced (Irbins, 2009).

Pellets are environmentally friendly renewable biofuel, and they are CO_2 neutral, because biomass raw materials, used for the production thereof, during a growth attracts the same amount of CO_2 that is released during burning of the product. As biofuel wood pellets are environmentally friendly also due to the fact that they contain such a small amount of sulphur and nitrogen that, when correctly burnt, amounts of nitrogen oxide and sulphur dioxide practically cannot be detected in gases.

Pellets are biomass dried and pressed to the size that can be easily transported, stored, efficiently burnt and may ensure fully automatic burning process. Woodchip pellets or fuel pellets are solid biofuels, chemical transformation-combustion of which results in a conversion to heat. Pellets are made from dried woodworking residues and waste: sawdust, wood shavings, barks, twigs, branches, etc. One kilogram of wood pellets contains energy equal to 0.5L of liquid fuels (Irbins, 2009).

Pellets have high thermal efficiency - the new pellet burning technologies allow burning woods with very high efficiency (88 – 92%). Pellet heating capacity is only 10% lower than that of coal. Pure and natural raw materials used for the pellet production are sawdust, woodchips, and wood. For granulation, a variety of herbaceous species, their mixtures, natural meadow grass, and reeds can be used (Adamovičs et al., 2009; Enerģētisko …, 2007; Lazdiņa et al., 2008).

In addition, the biomass dried in the pellet manufacturing process is compacted in proportion from 1:7 to 1:10 of the initial biomass volume. If compared to wood, one pellet unit volume has two times more calories than the same volume of wood.

Even if perfectly dried, firewood contains 20-30% more moisture than a pellet. As a result, due to the fact that 'air' and 'water' are not transported, the transportation of pellets is much more effective than transportation of any other biomass.

The highest quality pellets have natural wood colour, they are clean, pleasantly fragrant and smooth. Pellets for heating are produced from 100% natural material-wood shavings. Pellets are cylindrical in shape and approximately as thick as a pencil (Irbins, 2009).

Pellets have several advantages, if compared to their raw material - wood shavings - because they are more compact, more easily transportable and, the most important, they can be obtained from wood residues and therefore pellets are produced from are renewable resources. Wood combustion process is less harmful: carbon dioxide released to the atmosphere does no shift balance in nature, and does not increase the greenhouse effect, unlike black fuel oil or fossil fuels (Tardenaka and Spince, 2006).

The studies show that, if residential houses are heated with pellets instead of black fuel oil, the released CO_2 pollution is reduced by about 4.8 tons per year, but substitution of gas-fired central heating leads to the reduction of the emitted CO_2 by approximately 2.5 t per year. Transportation and storage of pellets does not pose risk for the environment. Ash generally can be used as chemical fertilizers, since chemical elements in its content usually do not exceed the specified limits (Enerģētisko …, 2007).

Increase of biomass on the Earth every year is valued as 200 billion tonnes. Although biomass energy potential is 10 times higher than possibilities of fossil fuels, still the use of biomass is very complicated. In comparison with the fossil fuel, the natural fuel has lower heat output. For fresh carved wood it is 2.9, for dry - 4.28, for cardboard - 4.39, for black fuel oil - 11.73, for coal from - 6.5 to 9, and for natural liquefied gas - 14.33 kWh kg^{-1}. Technologies for the use of biomass are constantly improved, but fossil fuel resources are running short, so in future we can expect faster price rises. For the past 15 years, the heat and power generation from biomass in the EU countries has been increasing by 2 - 9% per year, while currently biomass constitutes only about 5% of the total energy produced (Zaķe et al., 2010).

At present wood products (firewood, woodchips, and pellets) are the most popular renewable fuels in Latvia. However, also wood resource regeneration ability is limited in time and space. In many countries cultivation of various plants is recommended as an alternative to the thermal energy production (Adamovičs et al., 2009; Белосельский and Соляков, 1980).

One of the alternatives used for the biomass production is cultivation of grasses (*Phalaris arundinacea* L., *Festuca arundinacea* L., etc.). Evaluating the reed canary grass as a fuel, it should be noted that it is very suitable for the use in automatic boilers.

However, use of the reed canary grass for the heat production is characterized by major problems in burning process, such as the quantity of ashes, composition of flue gases and ash melting temperature (Boateng et al., 2006).

Production of thermal energy (from pellets) would need cultivated plants with high biomass yield, good combustibility, higher heat output and lower content of ashes. Finding the most appropriate reed canary grass composition (reed canary grass biomass together with biomass osier and poplar biomass) with the best pellet combustion ability will result in the best and the most efficient solution. And perhaps in future there will be economies specializing directly on cultivation of reed canary grass intended for heating and its use in the manufacture of pellets.

One of the most significant indicators of the fuel material quality is ash. However, larger quantities of ash are causing problems with automation of the combustion process (Tardenaka and Spince, 2006).

The most important indicator in the production of thermal energy is the quantity of ashes, which according to the standard (DIN 51731) rates up to 15 g kg^{-1}. Higher ash contents are causing problems with automation of the combustion process. In addition, heating capacity of such pellets is 600 – 1000 kJ kg^{-1} lower, for example, for the bark briquettes having ash content of 140 g kg^{-1} heating capacity comprises 16711 kJ kg^{-1} (by the standard DIN 51731, net calorific value must reach at least 17500 kJ kg^{-1}). Fuel combustion heat is a key performance indicator, which largely depends on the amount of moisture and ashes. At mean granule moisture of 67 – 78 g kg^{-1} it ranges from 18400 to 17700 kJ kg^{-1}.

New standards for the production of pellets-DIN Plus-indicate that ash content must not exceed 0.5% (Tardenaka and Spince, 2006).

Wood ashes have almost a full set of minerals required by the plants. They contain macro-elements (except nitrogen) and trace elements in the form of oxides and carbonates. Wood ash, depending on the tree specie, contain 40 – 200 g kg^{-1} of potassium, 180 – 300 g kg^{-1} of calcium, and 5 – 10 g kg^{-1} of phosphorus. The effect left by the ash is lasting for three to four years; it can be used as a fertiliser annually, on average providing 300 - 400 g per square meter. Wood ash is a valuable source of minerals and high-quality alkali, containing more than 30 nutrients (potassium, calcium, magnesium, iron, phosphorus, sulphur, and

other elements) necessary for plants, and in a very short time it can reduce the soil acidity (Irbins, 2009).

Combustion ability is the primary characteristic of a fuel that determines its effectiveness (Friedl et al., 2005) - the maximum amount of energy that can be produced during the substance combustion. The highest combustion heat is the enthalpy of complete fuel combustion, that is, to achieve the maximum degree of oxidation. The highest combustion heat is determined by burning a sample in the calorimetric ball. The highest heat of combustion includes also the heat that is released at the water vapour condensation (Obenberger and Thek, 2010).

One of the most important indicators in the heat production is the amount of ashes. In compliance with the DIN 51731 standard for the assessment of pellets and briquettes elaborated in Germany, the norm has been specified up to 1.5%. Larger quantities of ashes are causing problems with the combustion process automation (Tardenaka and Spince, 2006).

Reed canary grass *(Phalaris arundinacea L.)* according to its characteristics and composition is similar to the wood, while when burning generates more ashes. Therefore, in the production of pellets it should be mixed with the shavings and chips.

Objectives of the research:

1. to examine and assess combustion ability of and ash content in the energy plant pellets (*Phalaris arundinacea* L./ *Salix viminalis* L. and *Phalaris arundinacea* L./ *Populus tremula* L.) with various proportions of components (1/3;1/1;3/1);
2. to assess the impact of nitrogen chemical fertilizers on the quality of pellets;
3. to determine the best combinations and proportions of the energy plant components.

The aim: to determine the burning capability of energy plant biomass pellets.

Materials and Methods

Research objects: reed canary grass (*Phalaris arundinacea* L.) - (RCG), energy plants: osier (*Salix viminalis* L.) and poplar *(Populus tremula* L.*)*.

In the territory of Latvia, reed canary grass (*Phalaris arundinacea* L.) biomass is regarded as one of the alternative sources of raw materials for the production of pellets in the Baltic States and Northern Europe. This grass is characterized by its stability under local climatic conditions and high biomass yield.

Samples (reed canary grass variety '*Marathon'* at N-90 kg ha^{-1} dose of chemical fertilizer) for the study were taken at Latgale Centre of Agriculture Science (*SIA Latgales lauksaimniecības zinātnes centrs*) on 06.10.2010.

Whereas cultivated energetic plants: osier (*Salix viminalis* L.) variety '*Tordis*' ((*Salix schwerinii* × *S. viminalis*) × S. *viminalis*) and poplar *(Populus tremula* L.*)* (N chemical fertilizer dose N-0 and N-120 kg ha^{-1}) were collected in the Vežaiči Agricultural Research Institute Centre (Lithuania) on 15.10.2010.

Pellets were made of single components and two components varied as follows:

Single-component pellets:

1. *Salix viminalis* L.,
2. *Populus tremula* L.,
3. *Phalaris arundinacea* L.

Two-component pellets in following proportions:

1/3 - 1 part RCG + 3 parts *Salix viminalis* L. or *Populus tremula* L.,

1/1 - half RCG + half *Salix viminalis* L. or *Populus tremula* L.,

3/1 - 3 parts RCG + 1 part *Salix viminalis* L. or *Populus tremula* L.

In the pellet manufacturing process the energy plant biomass is chopped and ground in the laboratory mill ЭМ-3А УХЛ 4.2, and afterwards powder produced in a mill is formed into a pellet with the hand press 'IKA WERKE'.

Energy plant biomass pellets were made from 100% natural ingredients – chopped wood (*Salix viminalis* L. or *Populus tremula* L.) and chopped RCG biomass. Pellets have cylindrical shape and they are approximately as thick as a pencil.

Combustion heat of the energy plant biomass pellet samples was determined calorimetrically with a calorimetric capsule IKA C 5003 in Klaipėda University scientific -research laboratory, in compliance with the LST CEN/TS 14918:2006 standards.

Ash content in different composition samples was found out in the agricultural scientific laboratory for agronomic analyses of the University of Latvia in compliance with the ISO 5984: 2002/Cor 1: 2005 standard. For each sample three parallel experiments were carried out.

The mathematical evaluation was performed with the help of three experiments taking place simultaneously.

Results and Discussion

Evaluation of the medium calorific capacity of the sample with the ingredient proportion 1/3 (RCG/ *Populus tremula* L.) show that it was significantly higher ($p<0.05$) (19.01%), if compared to (*Salix viminalis* L.) ($RS_{0.05A}=0.08$).

Comparison of the obtained results show that significant ($p<0.05$) is ratio $RS_{0.05B}=0.14$. But considering the fertilizer effect on combustion, it appears that there are significant differences ($p<0.05$) ($RS_{0.05A}=0.08$).

The highest combustion heat indicators were observed for peat: 28.8 MJ kg^{-1}, moreover the number is very close to the coal index. The straw biomass had the highest combustion heat indicators - 17.3÷18.5 MJ kg^{-1}, wood (various tree species) combustion heat comprised 18.5÷19.5 MJ kg^{-1}, wood bark - 18.5÷19.5 MJ kg^{-1}, and canola - 18.6÷19.6 MJ kg^{-1} (Zaķe et al., 2010).

When analyzing combustion ability of different proportion reed canary grass and osier pellets, depending on the dose of nitrogen chemical fertilizers, we came to the conclusion that best combustion ability was indicated in samples without the dose of nitrogen chemical fertilizers.

Best combustion ability indicators were found in the combination 1/3 (RCG /*Populus tremula* L.) - 18.59 MJ kg^{-1} with nitrogen chemical fertilizers and 18.83 MJ kg^{-1} without the dose of nitrogen chemical fertilizers (Fig. 1).When analyzing combustion ability of different composition reed canary grass and osier pellets, depending on the dose of nitrogen chemical fertilizers, we found out that the best combustion ability was in samples without the dose of nitrogen chemical fertilizers. The best combustion ability is indicated at 1/3 (/RCG/*Salix viminalis* L.) with a nitrogen fertilizer - 18.57 MJ kg^{-1}, but without a dose of nitrogen chemical fertilizers - 18.69 MJ kg^{-1} (Fig. 2).

Consequently, nitrogen chemical fertilizers are not of vital importance, therefore for clearness the average results of combustion capacities in pellets with different compositions were displayed in Figure 3.

The research shows that 100% RCG biomass is having lower combustion ability than pellets with osier and poplar. The best reed canary grass biomass combustion ability indicators are presented on samples with ratio 1/3 (/RCG/*Salix viminalis* L.) - 18.71 MJ kg^{-1}, 1/3 (RCG/*Populus tremula* L.) - 18.63 MJ kg^{-1}.

Heating with lower ash content allows operating with economically higher quality heating systems. In Latvia amount of ashes from wood chip pellets and briquettes ranges within limits from 2.5 to 10 g kg^{-1}.

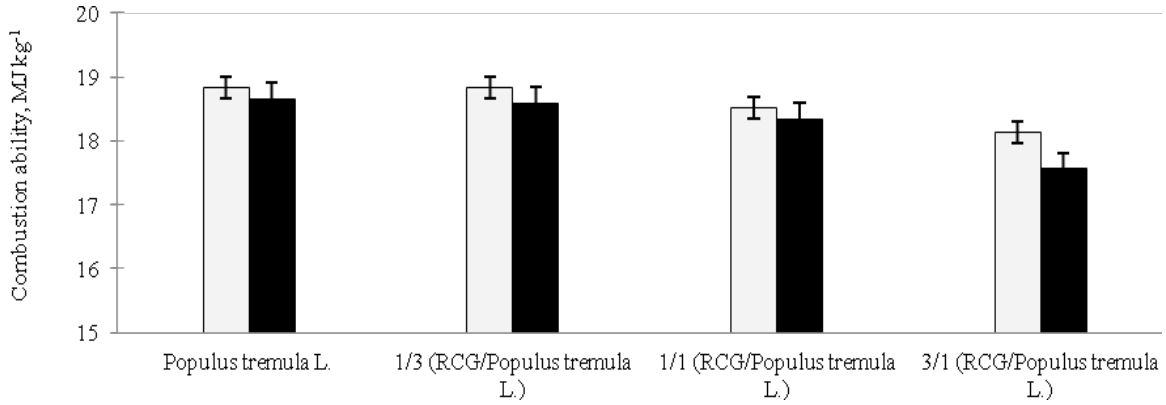

Figure 1. Combustion ability of osier and reed canary grass pellets depending on the nitrogen chemical fertilizers: □ -without mineral nitrogen fertilizer; ■ - with mineral nitrogen fertilizer.

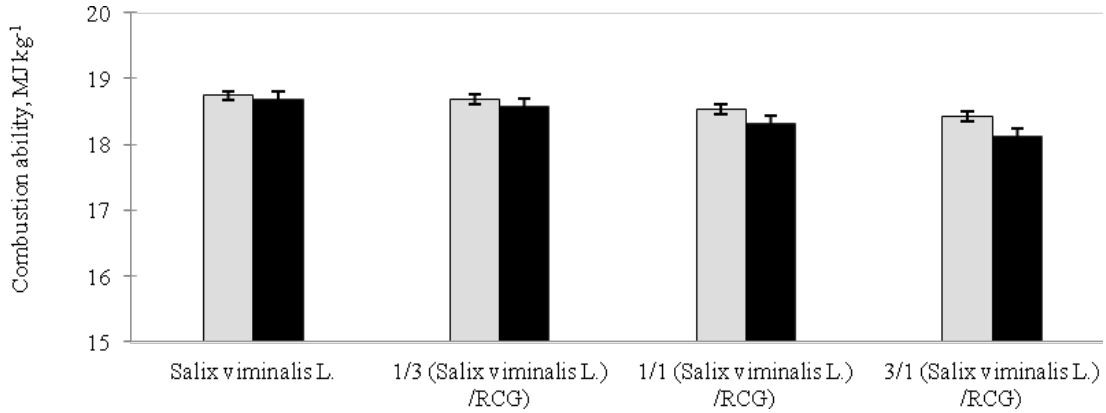

Figure 2. Combustion ability of poplar and reed canary grass pellets depending on nitrogen chemical fertilizers**:**
□ - without mineral nitrogen fertilizer; ■ - with mineral nitrogen fertilizer.

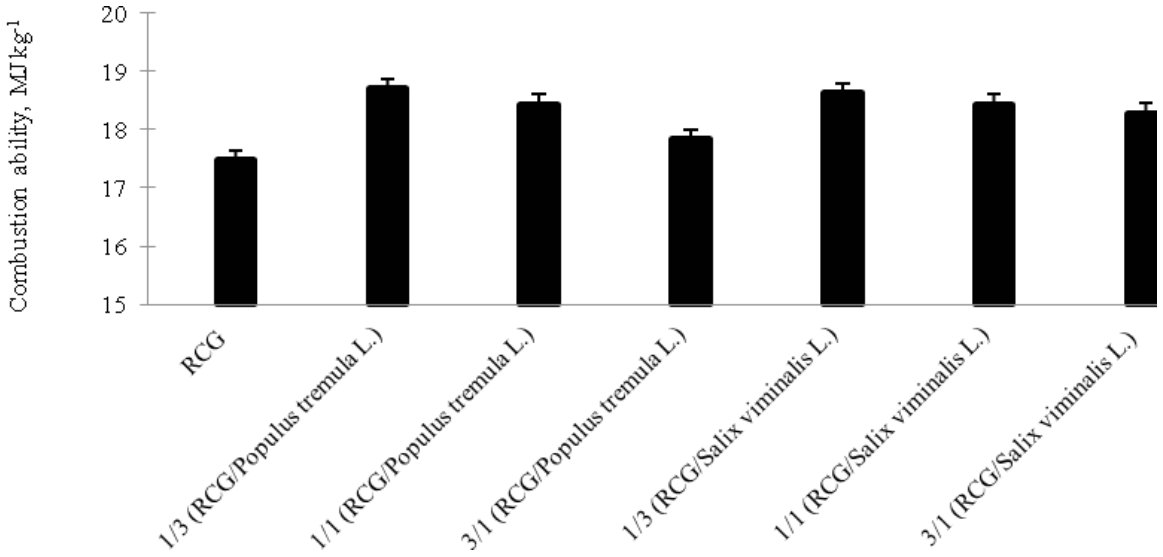

Figure 3. Combustion ability in pellets with different component proportions.

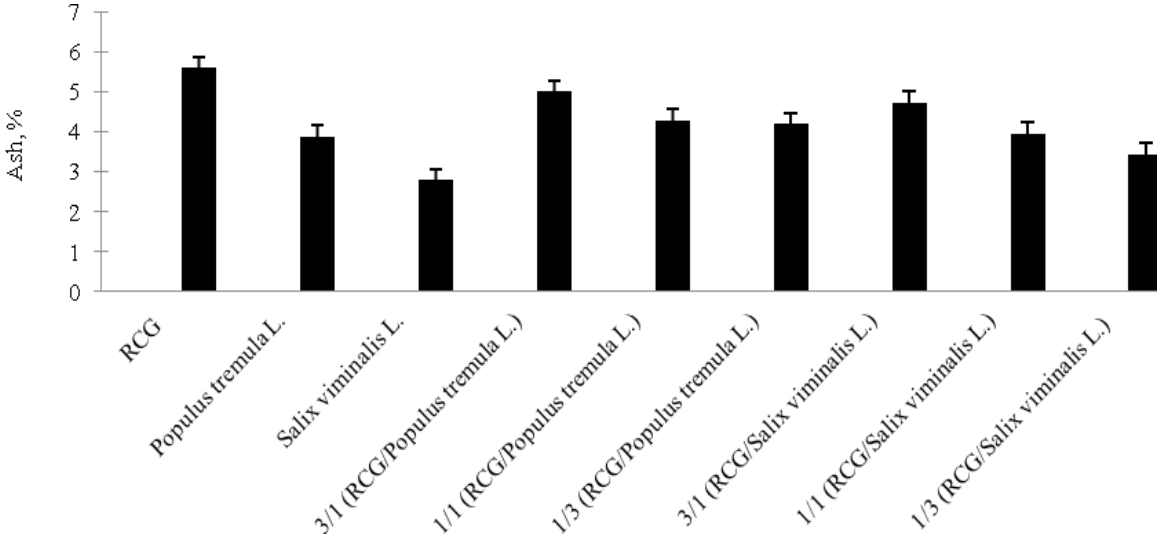

Figure 4. Ash content for different content of pellets.

In addition, the heating capacity of such pellets is 600–1000 kJ kg^{-1} lower, e. g. heating capacity for bark briquettes with ash content of 140 g kg^{-1} comprises 16.554 kJ kg^{-1} (according to the standard DIN 51731 heating capacity should reach at least 17.500 kJ kg^{-1}). Fuel combustion heat is an essential quality indicator, which largely depends on the amount of moisture and ashes. With the average pellet moisture comprising 67–78 g kg^{-1} it ranges from 18.400 to 17.700 kJ kg^{-1} (Obenberger and Thek, 2010).

Available data suggest that ash content produced by the autumn reed canary grass (*Phalaris arundinacea* L.) biomass is large - 55.9 g kg^{-1} (Fig. 4), therefore it should be appropriate to produce pellets from the reed canary grass biomass with the wood raw material supplement.

Thus one of the main problems during burning process in the heating system - the ash content - will be reduced. Therewith economic production and use of the reed canary grass in the heat production would be increased.

During the interpretation of the ash content indicators in pellets with different component proportions, we have identified that in part of the reed canary grass biomass the ash content is the lowest - respectively in the ones where indicators are proportional to the component combination 1/3 (RCG + wood) with both osier (34.3 g kg^{-1}) and poplar (41.8 g kg^{-1}).

Conclusions

Two variance analysis results showed that combustion can significantly influence ($p<0.05$) interaction of both factors (proportion and fertilizer) ($RS_{0.05AB}=0.20$), ($\eta^2=0.2026$), still the fertilizer impact was essential.

The largest average combustion ability of the reed canary grass biomass was for pellets with component ratio 1/3 (RCG/wood), reaching 18.76 MJ kg^{-1}, therefore it is appropriate to grow and use reed canary grass as an alternative energy plant cultivated for the production of biofuel pellets in Latvia.

The best component composition used for the production of pellets is the ratio 1/3 (RCG + wood). The lowest ash content was for a mixture of various granules with the average ratio 1/3 (RCG/*Salix viminal* L) - 34.9 g kg^{-1} and also 1/3 (RCG/*Populus tremula* L.) - 41.8 g kg^{-1}.

Nitrogen fertilizers do not leave significant effect on the quality of pellets and their combustion ability. Average combustion ability of pellets of different sizes without nitrogen fertilizers comprised 18.53 MJ kg^{-1}, but with nitrogen fertilizer - 18.34 MJ kg^{-1}.

Acknowledgements

Project 'Attraction of human resources to the research of the renewable energy sources', Agreement No 2009/0225/1DP/1.1.1.2.0/09/APIA/VIAA/129

References

1. Adamovičs A., Dubrovskis V., Plūme I., Jansons Ā., Lazdiņa D., Lazdiņš A. (2009) Biomasas izmantošanas ilgtspējības kritēriju pielietošana un pasākumu izstrāde (Criteria for biomass use sustainability and development of measures), Vides projekti, Rīga, 126–141. lpp. (in Latvian).
2. Boateng A.A., Jung H.G., Adler P.R. (2006) Pyrolysis of energy crops including alfalfa stems, reed canary grass, and eastern gamagrass. *Fuel*, Vol. 85, No 17–18, pp. 2450–2457.
3. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC) (2009) Available at: http://ec.europa.eu/energy/renewables/transparency_platform/doc/national_renewable_energy_action_plan_latvia_lv.pdf, 15 February 2012 (in Latvian).
4. Enerģētisko augu audzēšana un izmantošana (Cultivation and use of energy crops) (2007) Adamovičs A., Agapovs J., Aršanica A. Daņiļevičs A., Dižbite T., Dobele G., Dubrovskis V., Iesalnieks V., Jure M., Kronbergs Ē., Lazdiņa D., Lazdiņš A., Teliševa G., Urbanovičs I., Varika A., Vederņikovs N., Zandersons J., Žūriņš A. Valsts SIA 'Vides projekti', ISBN 978-9984-9902-7-9, Rīga, 57–87. lpp. (in Latvian).
5. Friedl A., Padouvas E., Rotter H., Varmuza K. (2005) Prediction of heating values of biomass fuel from elemental composition. *Analytica Chimia Acta*, 544, pp. 191–198.
6. Irbins P. (2009) Biomasa – nākotnes enerģijas avots (Biomass – the future energy source). Available at: http://irbins.wordpress.com/2009/08/14/biomasa_02/, 17 January 2012 (in Latvian).
7. Lazdiņa D., Lazdiņš A., Bārdulis A. (2008) Daudzgadīga stiebrzāļu energokultūra - miežabrālis (Perennial grasses energy crop - reed canary grass). LVMI 'Silava', ISBN 978-9934-8016-3-1, Rīga, 3–7. lpp. (in Latvian).
8. Obenberger I., Thek G. (2010) The Pellet Handbook. The production and thermal utilisation of biomass pellets. London; Washington, DC: Earthscan, 2010, pp. 324–329.
9. Tardenaka A., Spince A. (2006) Characterization of fuel granules and briquettes produced from fine-dispersed wastewood. In: Vīksna A., et al., *International conference: Eco-Balt 2006, May 11-12,* Rīga, pp. 37–38.
10. Zaķe M., Barmina I., Līckrastiņa A., Valdmanis J., Abricka M., Suzdaļenko V., Cipijs A., Purmalis M., Valdmanis R., Teliševa G., Dižbite T., Dolacis J., Bikovens O., Aršanica A., Jašina L., Solodovņiks V., Andersone A., Janceva S., Volperts A. (2010) Dažādas izcelsmes atjaunojamo kurināmo maisījumu jauna veida granulētu produktu izveidošana ekoloģiski tīru un efektīvu degšanas un siltuma ražošanas procesu nodrošināšanai ar būtiski uzlabotu šo procesu tehnoloģiju (Development of new-type pelleted products from a mixture of different renewable fuels for ecologically clean and effective combustion and heat production processes with the help of significantly improved process technology), Available at: http://ipul.lv/main/combustion/majas_lapa_2.pdf, 10 March 2012 (in Latvian).
11. Белосельский Б.С., Соляков В.К. (1980) Энергетическое топливо (Energy Fuel), Энергия, Москва, 114–132 с. (in Russian).