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THE ANTI-NUTRITIONAL FACTORS OF LEGUMES AND THEIR TREATMENT POSSIBILITIES: A REVIEW

***Kristine Ozolina, Inga Sarenkova, Sandra Muizniece-Brasava**
Latvia University of Life Sciences and Technologies, Latvia
*Corresponding author's e-mail: kristineozolina7@gmail.com

Abstract
Today the demand for plant-based protein is growing rapidly due to increased awareness of animal protein growing costs and limited supply and has been highly related to biodiversity loss, climate change, and freshwater depletion. Legumes are in demand for their high content of protein, minerals, vitamins, and carbohydrates, also including dietary fibre. Legumes are rich not only in macronutrients and micronutrients but also contain anti-nutritional factors. One of the most important anti-nutritive properties of legumes is their high trypsin activity. The length of time required for the preparation of legumes has limited their frequency of use compared to recommended intake levels. By heat treatment, an anti-nutritional component in legumes can be mostly separated. The possibility of using extrusion cooking, microwave dryer, roasting equipment, etc., is widely studied. Roasting is one of the widespread methods for treatment of legumes that significantly enhances the texture, flavour, colour, and product appearance. The latest studies in the legume treatments report valuable results after the combined treatments, wet roasting, which includes: dehulling, soaking, and roasting. Heat treatment can be a potential way to improve legumes use in food production: reducing the time required for treatment, preparation and improving nutritional value.
Key words: legumes, protein, plant-based, roasting, heat treatment, anti-nutrients.

Introduction

The need for plant-based proteins is rapidly growing with raised awareness of the carbon footmark caused by meat and dairy-based foods, as plant-based foods have smaller carbon footmarks. Legumes are in the spotlight among all plant-based protein sources and play an important role in human nutrition for their high composition of protein, minerals, starch, vitamins, and carbohydrates, including dietary fibre. Legumes are particularly important since the utilization of animal-based proteins is limited due to restricted affordability or ethical, religious, and nutrition habits (Pasqualone *et al*., 2020; Park *et al*., 2020; Lignicka & Galoburda, 2022).

Although many legumes are nutritious, it is difficult to cook them. This is due to high amylose content starch forming up to 32% of the legumes composition (Gani *et al*., 2016). Among these starch molecules, there are hydrogen bonds that make the legumes, especially beans, very dense, and a high energy capacity is required to smash this hydrogen bonds structure by cooking treatment (Du *et al*., 2014). There are many treatments performed to carry off, that legumes for the human organism are eventually digestible, mainly fully free of anti-nutritional factors, such as lipoxygenases, trypsin inhibitors, and glycoproteins, as lectin, vicin or convicin. Compounds in legumes such as tannins, polyphenols, and phytic acid have been mentioned in terms of their effect on the human organism and should be considered too. Anti-nutrients are the binders that make a bond with the nutrient substances in the food and make those food compounds less accessible for absorption in the human body (Samtiya *et al*., 2021).

Anti-nutrients can be removed or decreased via numerous treatments of the legumes such as soaking, germination, heating, and fermentation. Soaking is the most economical and easiest treatment, in addition, to considering the anti-nutritional factors inactivation. The dehull is used in terms of protein enrichment in peas and beans (Mohamed *et al*., 2011a; Jiang *et al*., 2016; Samtiya *et al*., 2021). To tackle these anti-nutritional issues, there is an increasing demand to develop an efficient treatment methods for advanced legume utilization; thus, the present study aimed to review research findings for treatment methods for legumes as well as innovative and structured technology resolutions for cost reduction including maximum removal of anti-nutritional compounds.

Materials and Methods

Monographic method was used for this review. The review recapitulates results of advantages and disadvantages of legumes and their treatment possibilities. Literature mainly from nutritional scope of different scientific journals from Scopus, Web of Science and ScienceDirect data bases was used in development of the study. Studies were selected by key words, like legume anti-nutritional factors, treatments of legumes. More than 100 research was found, but only 38 research from the last ten years and 8 research older than ten years were used for the review, because they contained valuable information related to this study's aim. The review includes material from research conducted in India, China, Australia, Greece, Egypt, Iran, Germany, etc.

Results and Discussion

Advantages and disadvantages of legumes

In the menu of legumes for humans, lentils, peas, millet, peanuts, lupines and varied botanical classifications different types of beans, also soy (Kinyanjui *et al*., 2015; Park *et al*., 2020; Schmelter, Rohm, & Struck, 2021) are included. Soybeans

(*Glycine max L.*) are the first most harvested legumes in the world, next second place is taken by peanuts (*Arachis hypogaea L.*) providing an important nutrition source for humans (Jiao *et al*., 2014). The legume protein content depends on botanical classification and is 50%–200% higher compared to grain protein content (Simons & Hall, 2018). The legume fat content is low and purely exceeds 4 g per 100 g of dry matter, but not for soybeans (*Glycine max L.*) (Schmelter, Rohm, & Struck, 2021). Lupines (*Lupinus L.*) contain a higher fat content up to 15 g per 100 g and chickpeas (*Cicer arietinum L.*) contain up to 7 g per 100 g. Legumes have a relatively low fraction of sulphur-containing amino acids, such as methionine and cysteine. Legumes are a good source of dietary fibre, proteins, B group vitamins, starch and minerals. Starch is the main component in the dry matter of legumes, like all plant-based seeds and legume mineral content is between 3-5 g per 100 g of dry matter (Rebello *et al*., 2014; Simons & Hall, 2018; Lignicka, & Galoburda, 2022).

A nutritional disadvantage of legumes is that they contain anti-nutrients, they are known as compounds that by themselves or through their metabolic products arise in living systems, obstruct food utilization and have an effect on the health of animals and humans (Mohamed *et al*., 2011a). Non-protein amino acids, protease inhibitors, lecithins, phenolic substances, flatulence produces, saponins, and non-starch polysaccharides are the most popular anti-physiological compounds in legumes (Mohamed *et al*., 2011a). Protease inhibitors are widespread compounds reducing digestibility by blocking trypsin or chymotrypsin. Trypsin inhibitors inhibit the proteolytic activity of the digestive enzyme trypsin, thus reduce or prevent protein digestibility (Gulewicz *et al*., 2014). Phytic acid decreases mineral absorption. The complex formed from phenolic compounds or their oxidized products connected with enzymes, essential amino acids, and other proteins, thereby decreasing protein digestibility and nutrition value (Grela *et al*., 2017). Human organism does not have the capability to hydrolyse phytate and has no capability to absorb it; thus, phytate implicates in causing less bioavailable minerals. Phytate negatively acts on the bioavailability of positive ions such as Fe^{2+}, Fe^{3+}, Zn^{2+}, Ca^{2+}, and Mg^{2+} divalent and trivalent minerals by being negatively charged (Gemede & Negussie, 2014; Samtiya *et al*., 2021). Phenolic compounds in legumes can span from simple molecules (phenolic acids) to highly polymerized compounds (tannins) that may impair protein bioavailability (Karkanis *et al*., 2018). Tannins could decrease iron absorption by setting up a bond with protein and creating a complex. Intake of high concentrations of tannins can cause side effects such as proteins, essential amino acids, and specific tissue elimination from the human body, and induce gastrointestinal tract damage (Adeyemo & Onilude, 2013). Flavonoids are announced to be the most plentiful polyphenols in human nutrition and legumes contain them, too (Mohamed *et al*., 2011b). In the human colon, high quantity of polyphenols may inhibit reproducing of significant colon microorganisms (Samtiya *et al*., 2021). Lingyan et al. (2017) emphasize that some polyphenols in high amounts can also have a genotoxic or carcinogenic trait. Dietary polyphenols can inhibit iron absorption and decrease folic acid and thiamine motion in human organism (Samtiya *et al*., 2021).

Additional disadvantage is also the unpleasant 'beany flavour' of untreated faba bean (*Vicia faba L.*); thus in food use, this bean has been commonly limited. Faba bean (*Vicia faba L.*) is rich in proteins and due to the activity of endogenous enzymes can cause unpleasant 'beany flavour'; thus, their utilization in foods gives challenges regarding the quality of the sensory of legumes. Lipoxygenase is an enzyme which catalyses the oxidation of fatty acids, like linolenic and linoleic acids into hydroperoxides. Bean tissues also have peroxidases that catalyse various oxidation-reduction reactions that have an impact on lipids. Peroxidase is generally used to appoint the conformity of heat treatments, because it is usually the most heat-stable enzyme in plants. To resolve the faba beans (*Vicia faba L.*) 'beany flavour' issue, it is suggested to use treatment with microwave heating, steaming, kilning, oven heating, and autoclaving (Jiang *et al*., 2016; Sun *et al*., 2020). Besides, not fully cooked kidney beans (*Phaseolus vulgaris L.*) can be toxic to human health, since the existence of the naturally occurring toxin phytohemagglutinin. The usage of partially cooked kidney beans (*Phaseolus vulgaris L.*) in human food can guide to food poisoning, including nausea, gastroenteritis, and diarrhoea. The inactivation of phytohemagglutinin is also disturbed by the dense structure of the kidney bean (*Phaseolus vulgaris L.*) (Sun *et al*., 2020).

Another reason is that legumes require prolonged soaking and cooking treatments; thus, they are not valued by all consumers (Karkanis *et al*., 2018). Also, the application of legumes in baked products has increased significantly due to the challenges of the growing amount of population that has coeliac disease (Simons & Hall, 2018). Legume flour is noticed as an alternative raw material for baked products because of its high content of fibre and protein (Karkanis *et al*., 2018).

The reasons for the strengthened growth of legumes are mostly high agricultural sustainability aspects like the fact that they can be considered as highly nutritious and the symbiotic fixation of atmospheric nitrogen (Schmelter, Rohm, & Struck, 2021). Thus, to get rid of disadvantages and highlight valuable in legumes, it is important to use the correct treatment methods.

Treatment possibilities of legumes

Separation of unpleasant components in legumes is highly required to improve sensory acceptability and nutritional quality, and help effectively cultivate their potential as plant-based food for humans (Mohamed *et al*., 2011b). Various food treatment methods such as soaking, germination, cooking, dehulling, and fermentation are known to increase the nutritional quality of legumes and also decrease anti-nutritional factors successfully (Mohamed *et al*., 2011a). The most effective treatment to get rid of anti-nutritional compounds in legumes are germination and fermentation, but their usage remains limited due to the certain sensory properties they cause and the additional work-load they involve (Mohamed *et al*., 2011b).

Different physical treatments have been proposed to remove or decrease anti-nutritional factors in legumes. The physical treatment involving soaking and cooking strongly improve legume nutritive value; see used methods in Table 1.

Table 1

Summary of the most productive treatment methods of legumes

Treatment	Procedure	Legumes	Reference
Pretreatment methods			
Soaking	Soaked in distilled water 1:10 w v^{-1}. Room temperature ~25 °C. 24 h.	Soybean *(Glycine max L.)*, mung bean *(Vigna radiate L.)*, kidney bean *(Phaseolus vulgaris L.)*	Mohamed *et al*., 2011a, Mohamed *et al*., 2011b
	Soaked in different brine solutions with different pH (4, 5, 6, 8, 8.5). Included: 0.1 mol L^{-1} monovalent (Na_2CO_3, $NaHCO_3$, NaCl), 0.1 mol L^{-1} divalent ($CaCl_2$) salts and deionized water. At 25 °C for 6 h.	Beans *(Phaseolus vulgaris L.):* rose coco, red haricot, zebra, canadian wonder, soya fupi, pinto, Mwezi moja, gwaku, new mwezi moja	Kinyanjui *et al*., 2015
Dehulling	Hulls were removed manually after soaking	Soybean *(Glycine max L.)*, mung bean *(Vigna radiate L.)*, kidney bean *(Phaseolus vulgaris L.)*	Mohamed *et al.,* 2011a, Mohamed *et al.,* 2011b
	The hulls were removed manually after being cracked with stones in a stone mill	Faba bean *(Vicia faba L.)*	Jiang *et al*., 2016
Biotechnological methods			
Germination	Soaked in ethanol for 1 min, then soaked in distilled water (ratio 1:10 w v^{-1}). ~25 °C temperature. 12 h. Germinated in the dark for 5 days	Soybean *(Glycine max L.)*, mung bean *(Vigna radiate L.),* kidney bean *(Phaseolus vulgaris L.)*	Mohamed *et al.,* 2011a, Mohamed *et al.,* 2011b
Lactic Acid Fermentation	Samples 1:10 (dry legumes: water w v^{-1}). Sterilized for 15 min at 121 °C. The flasks were inoculated with 0.5 ml of activated Lactic Acid bacteria strains (1%) and fermented at 37 °C for 72 h	Soybean *(Glycine max L.)*, mung bean *(Vigna radiate L.)*, kidney bean *(Phaseolus vulgaris L.)*	Mohamed *et al.,* 2011a, Mohamed *et al*., 2011b
Milling methods			
Pin-disc milling	Beans were milled with a laboratory pin-disc mill set up to achieve minimum gap between pin-discs	Faba bean *(Vicia faba L.)*	Jiang *et al.,* 2016
Roller milling	Milled with a roller mill to gain “roller milled flours”	Faba bean *(Vicia faba L.)*	Jiang *et al*., 2016
Ultra-centrifugal milling	Beans were milled with a high speed rotor ultra-centrifuge mill equipped with a ring sieve (pore size 0.5 mm) and with 12000 rpm rotation speed	Faba bean *(Vicia faba L.)*	Jiang *et al*., 2016

Continuation of the Table 1

Treatment	Procedure	Legumes	Reference
Cooking methods			
Boiling	Beans were boiled in distilled water at 100 °C (ratio of 1:10 w v^{-1}) on a hot plate until 90 min	Soybean *(Glycine max L.),* mung bean *(Vigna radiate L.),* kidney bean *(Phaseolus vulgaris L.)*	Mohamed *et al.,* 2011a, Mohamed *et al.,* 2011b
	Beans were boiled at 96 °C in a thermostatic water bath (WBU–45; Memmert, Schwabach, Germany) for 2 h	Beans *(Phaseolus vulgaris L.):* rose coco, red haricot, zebra, canadian wonder, soya fupi, pinto, mwezi moja, gwaku, new mwezi moja	Kinyanjui *et al.,* 2015
Sterilization	Beans were sterilized in distilled water (ratio 1:10 w v^{-1}) at 15 atm, 121 °C for 10 min	Soybean *(Glycine max L.),* mung bean *(Vigna radiate L.),* kidney bean *(Phaseolus vulgaris L.)*	Mohamed *et al.,* 2011a, Mohamed *et al.,* 2011b
Microwave cooking	Beans were added in a Birex pot filled with distilled water (ratio 1:10 w v^{-1}), then cooked for 15 min in a microwave oven	*Soybean (Glycine max L.), mung bean (Vigna radiate L.), kidney bean (Phaseolus vulgaris L.)*	*Mohamed et al., 2011a, Mohamed et al., 2011b*
	Microwave oven used at 950 W. With 2, 3, 4, 6, 8 heating rounds, for 1, 1.5, 2, 3, 4 min, accordingly	Faba bean *(Vicia faba L.)*	Jiang *et al.,* 2016
Drying	A pilot-scaled fluidized bed dryer with inert particles with dielectric heating source. 35–65 °C.	Broad bean *(Vicia faba L.)*	Hashemi, Mowla, & Kazemeini, 2009
	Dried with microwave hot air rolling bed dryer. Hot air speed 0.5 m s^{-1} and 60–80 °C, drum 5 rpm	Faba bean *(Vicia faba L.)*	Li *et al.,* 2022
Roasting	Roasting was performed in an infrared roaster. The power was 250–450W for 10–30 min	Peanut kernels *(Arachis hypogaea L.)*	Bagheri *et al*., 2019
	45 min of hot air assisted radio frequency roasting at 110–130 °C	Peanut *(Arachis hypogaea L.)*	Jiao *et al*., 2015
	Roasted in batches until surface of the peas achieved 150 °C and the moisture content reached ~7.0%.	Chickpea *(Cicer arietinum L.)*	Kotsiou *et al*., 2022
Oven heating	Beans were heated in an oven at 170 °C for 30 min	Faba bean *(Vicia faba L.)*	Jiang *et al*., 2016
	Heating was done dry, in a hot air oven at 75–175 °C for 60 min	Faba bean *(Vicia faba L.)*, Soy bean *(Glycine max L.)*	Bühler *et al.,* 2020
Extrusion cooking	Single-screw extrusion at 120–170 °C temperature with 50–240 rpm	Bean *(Phaseolus vulgaris L.)*	Espinoza-Moreno *et al*., 2016
	Twin-screw extrusion at 150 °C temperature with 200 rpm	Pea *(Pisum sativum L.)*	Koksel *et al*., 2018
	Single-screw extrusion at 160 °C temperature with 250 rpm	Chickpea *(Cicer arietinum L.)*	Hegazy *et al*., 2017
	Single-screw extrusion at 180 °C temperature with 210 rpm	Lentil *(Lens culinaris L.)*	Rathod *et al*., 2016
	Single-screw extrusion with 160–200 rpm heated up to 160–180 °C temperature	Cowpea *(Vigna unguiculata L.)*	Jakkanwar *et al*., 2018

Continuation of the Table 1

	Twin-screw extrusion with 200 rpm heated up to 140 °C temperature	Faba bean *(Vicia faba L.)*	Smith *et al.*, 2011
	Twin-screw extrusion at 130–170 °C temperature with 400–550 rpm.	Mung bean *(Vigna radiate L.)*	Yagci *et al.*, 2020
	Single-screw extrusion with 100–140 rpm heated up to 160–200 °C temperature	Pigeon pea *(Cajanus cajan L.)*	Chakraborty *et al.*, 2014

Pre-treatment of legumes

Legumes are mainly soaked in water for a few hours before cooking, fermentation or germination methods are used for treatment (Kinyanjui *et al.*, 2015). Soaking is a convenient way to decrease anti-nutrients (Samtiya *et al.*, 2021). Mohamed et al. (2011a) have explored that soaking beans could decrease the amount of trypsin inhibitor activity below the control value. Trypsin inhibitors activity was lower in kidney beans (*Phaseolus vulgaris L.*) around 18%, by soaking (Ramakrishna *et al.*, 2006). Khattab & Arntfield (2009) showed that peas (*Pisum sativum L.*) and kidney beans (*Phaseolus vulgaris L.*) notably decreased their trypsin inhibitor level by up to 10–19% by using a soaking treatment. Their results also represented variations in the level of trypsin inhibitor loss by different tested legumes soaking, and the highest loss of trypsin inhibitor was gained for kidney beans (*Phaseolus vulgaris L.*) (Mohamed *et al.*, 2011a). Soaking can be adopted by bean canners, particularly used by bean breeds that easily gap in the canning treatment. Soaking in low pH and in $CaCl_2$ solutions promote to enhance the firmness of the cooked beans and thereby prolong the cooking time (Kinyanjui *et al.*, 2015). The mechanism why cooking time in beans is prolonged is very complex. Gained results from Kinyanjui et al., (2015) study indicate that either bean hulls or pectin is the reason for such a long bean cooking time. Briefly, soaking beans for 24 hours gives a loss in total phenolic compounds reaching up to 31–55%. A less effective decrease in total phenolic compounds by soaking is in soybeans (*Glycine max L.*) compared to other tested beans like kidney (*Phaseolus vulgaris L.*) and mung beans (*Vigna radiate L.*) (Mohamed *et al.*, 2011b). Similar results in phenolic compound level changes were gained by Paramjyothi & Anjali (2005) for chickpeas (*Cicer arietinum L.*), Khandelwal et al. (2010) for Indian legumes, and Ramakrishna et al. (2006) for mung beans (*Vigna radiate L.*). Total phenolic compound reduction by soaking could simply be because phenolic compounds leach out in the soaking substance by the concentration gradient (Ramakrishna *et al.*, 2006). Xu & Chang (2008) mentioned that the situation of difference in a decrease in total phenolic compounds during the soaking treatment may be due to a contrast in the distribution and amount of phenolic compounds in the bean hulls, and cotyledon among the examined beans.

Dehulling means the outer covering removal of the legumes. It could be carried out manually by the usage of pestle and mortar. Nowadays, milling equipment is implemented. The application of dehulling reduces the amount of anti-nutritional compounds, such as phytic acid, tannins, and polyphenolic content (Samtiya *et al.*, 2021).

Biotechnological methods

Biotechnological methods such as germination and fermentation are used also for legume treatment.

Germination is an effective phase of metabolism wherein anti-nutrients are decreased; it is a biotechnological method where proteases break down cellular proteins, but it has only an average effect with regard to the decrease in the trypsin inhibitor especially. Germination may boost legume nutritional value by modifying the chemical composition and decreasing the anti-nutrient factors (Kumari, Krishnan, & Sachdev, 2015; Samtiya, Aluko, & Dhewa 2020).

Fermentation is also a biotechnological method where complex biomolecules are converted by microorganisms (specially selected yeast or bacteria strains) into simple molecules. Fermentation improves antioxidant properties and nutritional value of legumes. The fermentation effectiveness depends on the legume and the microorganism strain used on the lower level of anti-nutritional factors. Fermentation could eliminate few anti-nutritional factors, like phytic acid, and besides gives a positive result on bioavailability and protein digestion (Samtiya *et al.*, 2021).

Besides, genetic engineering methods are created to remove the genes which are responsible for metabolic pathways for decreasing the output or inactivation of the anti-nutrients (Kumar *et al.*, 2019).

Cooking methods

Different heating methods, such as boiling, sterilization, roasting hot air drying, and microwave cooking were used to reduce anti-nutrients significantly (Samtiya *et al.*, 2021).

The roasting application is more popular in nuts than in beans. Roasting forms desirable sensory properties and significantly improves the colour, flavour, texture, and appearance of nuts. Peanuts (*Arachis hypogaea L.*) after roasting have the potential to be used as snacks (Bagheri *et al*., 2019). The usage of the roasting method has more advantages, such as advanced product quality, high roasting capacity, prolonged shelf-life of product, and less environmental pollution. In general, the infrared roasting treatment is a successful alternative treatment for utilizing peanuts (*Arachis hypogaea L.*) as a snack and can be adapted also to roasting the beans (Bagheri *et al*., 2019). Overall, frying, electric furnace roasting, hot air roasting, and coal-fired furnace roasting are usually applied roasting treatments. All mentioned roasting treatment methods are time-consuming, have reduced production rates, and have high energy costs (Jiao *et al*., 2014).

Mostly all grain flours sold in food markets are milled with a roller-milling equipment, which could be applied to legumes too. Ultra-centrifugal milling mills produce fine flours with equable particle size dispensation, which is usually used in chemical compound analyses (Jiang *et al*., 2016). Microwave heating method successfully and quickly inactivates peroxidase and lipoxygenase in faba bean (*Vicia faba L.*), which are related to unpleasant 'beany flavour' (Jiang *et al*., 2016). Microwave heating for 1.5 min at 950 W power is sufficient to inactivate undesirable enzymes associated with 'beany flavor' and advance the milling quality of the legumes. Microwave heating has few preferences as it can reach high heating rates and has lower treatment time compared to oven-based heating methods (Chandrasekaran, Ramanathan, & Basak, 2013). Conventional oven heating for 30 min at 170 °C as well inactivates the lipoxygenase and peroxidase enzymes in legumes flour. All heating methods create starch protein aggregates from legumes flour, and they all are insoluble in water (Jiang *et al*., 2016).

Hydrothermal methods like extrusion using no chemicals are able to enhance the functional properties of legume flours, too (Patil *et al*., 2018). Extrusion cooking technology is known to decrease the amounts of several anti-nutrients contained in legumes such as trypsin inhibitors, tannins, phytic acid, and lectins. In addition, extrusion cooking is able to increase the digestibility of protein and starch, too (Pasqualone *et al*., 2020). Extrusion is a short time and high temperature method in which food is cooked in high temperature and automatic under pressure shear combination. This outcome with chemical reactions and molecular modification with the help of which functional properties, phytochemical structure, and nutrients of the food are transformed (Patil *et al*., 2018). Therefore, the extrusion of legumes is an applicable strategy to add value to underexploited legumes and shorten home preparation time, thus also increase the consumption of these sustainable legumes (Pasqualone *et al*., 2020).

The hot air-drying treatment for beans can be effective to gelatinize starch on their surface area, and also for moisture migration. The major reasons limiting the evolution of the hot air-drying method are as follow: drying is time-consuming and consumes high energy although this method is easy to operate and has low manufacturing cost, too (Li *et al*., 2022). However, the microwave radiation in the microwave drying treatment heats the surface and interior areas of the legumes at the same time, and these properties relieve starch gelatinization and free moisture removal by drying. Thus, the microwave drying method has the advantage of high drying productivity and low energy consumption compared with the conventional drying treatment (Haghi & Amanifard, 2008). Li and others (2022) explored that in a relatively short time the dried beans (*Vicia faba L.*) are fully cooked. Briefly, the optimum treatment properties to the dried beans (*Vicia faba L.*) are firstly beans should be soaked for 4h and steamed for 15 min, further followed by hot air drying at a microwave with 70 °C hot air.

All these cooking methods also reduce phytate, tannin, trypsin inhibitor and a protease inhibitor, and they eliminate tannins and phytates from legumes (Samtiya *et al*., 2021). Besides, the physico-chemical properties of starch transform performing treatment via reaction with macronutrients like lipids and proteins, and this gives a significant result on the texture of legume products (Lignicka & Galoburda, 2022).

To achieve greater results and obtain a set of several properties, mainly the sensory quality, and increase anti-nutrient removal, there is a need to apply legume treatment methods by combining them.

Conclusions

This study has shown the good traits of legumes using them as a source of protein. Legumes contain some anti-nutritional factors like tannins, polyphenols, phytate, and trypsin inhibitor; these may inhibit mineral absorption, induce toxicity. Accordingly, to gain beneficial nutrients from legumes, several treatments should be applied, such as soaking, dehulling, roasting, extrusion, boiling, germination, hot air drying, and fermentation which have proven to be effective. These are suitable treatments for eliminating anti-nutritional factors from legumes. Biotechnological methods are used on legumes to obtain legumes with low phytate levels. The most effective results could be gained by combining these treatments and reaching out with pleasant sensory quality and inhibited anti-nutritional factors fully from legume-based products.

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References

Adeyemo, S.M., & Onilude, A.A. (2013). Enzymatic reduction of antinutritional factors in fermenting soybeans by Lactobacillus plantarum isolates from fermenting cereals. *Nigerian Food Journal.* 31(2). 84–90.

Bagheri, H., Kashaninejad, M., Mohammad, Z.A., & Aalami, M. (2019). Textural, color and sensory attributes of peanut kernels as affected by infrared roasting method. *Information precessing in agriculture.* 6. 255–264.

Bühler, J.M., Dekkers, B.L., Bruins, M.E., Jan van der Goot, A. (2020). Modifying Faba Bean Protein Concentrate Using Dry Heat to Increase Water Holding Capacity. *Foods.* 9. 1077.

Chakraborty, S.K., Singh, D.S., & Kumbhar, B.K. (2014). Influence of extrusion conditions on the colour of millet-legume extrudates using digital imagery. *Ir. J. Agric. Food Res*. 53. 65–74.

Chandrasekaran, S., Ramanathan, S., & Basak, T. (2013). Microwave food processing – a review. *Food Research International.* 52. 243–261.

Du, S.K., Jiang, H., Ai, Y., & Jane, J.L. (2014). Physicochemical properties and digestibility of common bean (Phaseolus vulgaris L.) starches. *Carbohydrate Polymers.* 108. 200–205.

Espinoza-Moreno, R.J., Reyes-Moreno, C., Milán-Carrillo, J., López-Valenzuela, J.A., Paredes-López, O., Gutiérrez-Dorado, R. (2016). Healthy ready-to-eat expanded snack with high nutritional and antioxidant value produced from whole amarantin transgenic maize and black common bean. *Plant Foods Hum. Nutr.* 71. 218–224.

Gani, A., Jan, A., Shah, A., Masoodi, F.A., Ahmad, M., Ashwar, B.A., Akhter, R., Wani, I.A. (2016). Physico-chemical, functional and structural properties of RS3/RS4 from kidney bean (*Phaseolus vulgaris*) cultivars. *International Journal of Biological Macromolecules.* 87. 514–521.

Gemede, H.F., & Negussie, R. (2014). Antinutritional factors in plant foods: Potential health benefits and adverse effects. *International Journal of Nutrition and Food Sciences*. 3.4. 284–289.

Grela, E.R., Kiczorowska, B., Samolińska, W., Matras, J., Kiczorowski, P., Rybiński, W., Hanczakowska, E. (2017). Chemical composition of leguminous seeds: part I – content of basic nutrients, amino acids, phytochemical compounds, and antioxidant activity. *Eur. Food Res. Technol.* 243. 1385–1395.

Gulewicz, P., Martinez-Villaluenga, C., Kasprowicz-Potocka, M., & Frias, J. (2014). Non-nutritive compounds in fabaceae family seeds and the improvement of their nutritional quality by traditional processing - a review. *Polish J. Food Nutr. Sci.* 64. 75–89.

Haghi, A.K., & Amanifard, N. (2008). Analysis of heat and mass transfer during microwave drying of food products. *Brazilian Journal of Chemical Engineering.* 25(3). 491–501.

Hashemi, G., Mowla, D., & Kazemeini, M. (2009). Moisture diffusivity and shrinkage of broad beans during bulk drying in an inert medium fluidized bed dryer assisted by dielectric heating. *Journal of Food Engineering*. 92, 331–338.

Hegazy, H.S., El-Bedawey, A.E.A., Rahma, E.H., & Gaafar, A.M. (2017). Effect of extrusion process on nutritional, functional properties and antioxidant activity of germinated chickpea incorporated corn extrudates. *Am. J.Food Sci. Nutr. Res*. 4. 59–66.

Jakkanwar, S.A., & Rathod, R.P. (2018). U.S. Development of cowpea-based (*Vigna unguiculata*) extruded snacks with improved in vitro protein digestibility. *Int. Food Res. J*. 25. 804–813.

Jiang, Z., Pulkkinen, M., Wang, Y., Lampi, A.M., Stoddard, F.L., Salovaara, H., Piironen, V., Sontag-Strohm, T. (2016). Faba bean flavour and technological property improvement by thermal pre-treatments. *LWT – Food Science and Technology.* 68. 295–305.

Jiao, S., Zhu, D., Deng, Y., & Zhao, Y. (2014). Effects of hot air-assisted radio frequency heating on quality and shelf-life of roasted peanuts. *Food Bioprocess Technol.* 9(2). 308–19.

Karkanis, A., Ntatsi, G., Lepse, L., Fernández, J.A., Vagen, I.M., Rewald, B., Alsiņa, I., Kronberga, A., Balliu, A., Olle, M., Bodner, G., Dubova, L., Rosa, E., & Savvas, D. (2018). Faba bean cultivation – revealing novel managing practices for more sustainable and competitive European cropping systems. *Front. Plant Sci*. 9. 1–14.

Khandelwal, S., Udipi, S.A., & Ghugre, P. (2010). Polyphenols and tannins in Indian pulses: Effect of soaking, germination and pressure cooking. *Food Research International*. 43. 526–530.

Khattab, R.Y., & Arntfield, S.D. (2009). Nutritional quality of legume seeds as affected by some physical treatments 2. Anti-nutritional factors. *LWT – Food Science and Technology,* 42. 1113–1118.

Kinyanjui, P.K., Njoroge, D.M., Makokha, A.O. Christiaens, S., Ndaka, D.S., & Hendrickx, M. (2015). Hydration properties and texture fingerprints of easy-and hard-to-cook bean varieties. *Food Science & Nutrition.* (1): 39–47.

Koksel, F., & Masatcioglu, M.T. (2018). Physical properties of puffed yellow pea snacks produced by nitrogen gas assisted extrusion cooking. *LWT Food Sci. Technol.* 93. 592–598.

Kotsiou, K., Sacharidis, D.D., Matsakidou, A., Biliaderis, C.G., & Lazaridou, A. (2022). Physicochemical and functional aspects of composite wheat-roasted chickpea flours in relation to dough rheology, bread quality and staling phenomena. *Food Hydrocolloids* 124. 107322.

Kumar, A., Kumar, V., Krishnan, V., Alkesh, H., Marathe, A., Jolly, P.C.M., & Sachdev, A. (2019). Seed targeted RNAi-mediated silencing of GmMIPS1 limits phytate accumulation and improves mineral bioavailability in soybean. *Scientific reports*. 9(1). 1–13.

Kumari S., Krishnan, V., & Sachdev, A. (2015). Impact of soaking and germination durations on antioxidants and anti-nutrients of black and yellow soybean (Glycine max. L) varieties. *Journal of Plant Biochemistry and Biotechnology*. 24(3). 355–358.

Li, M., Wang, B., Lv, W., Lin, R., & Zhao, D. (2022). Characterization of pre-gelatinized kidney bean (*Phaseolus vulgaris* L.) produced using microwave hot-air flow rolling drying technique. *LWT – Food Science and Technology.* 154. 112673

Lignicka, I., & Galoburda, R. (2022). The Role of Cereal and Pulse Constituents and Processing Technology in Flake Texture Development: a Review. *Rural sustainability research.* 48(343); 34–44.

Lingyan, Z., Li, J., Han, F., Ding, Z., & Fan, L. (2017). Effects of different processing methods on the antioxidant activity of 6 cultivars of foxtail millet. *Journal of Food Quality.*

Mohamed, K.R., Abou-Arab, E.A., Gibriel, A.Y., Rasmy, N.M.H., & Abu-Salem, F.M. (2011b). Effect of legume processing treatments individually or in combination on their phytic acid content. *African Journal of Food Science and Technology.* 2. 36–46.

Mohamed, K.R., Gibriel, A.Y., Rasmy, N.M.H., Abu-Salem, F.M., & Abou-Arab, E.A. (2011a). Influence of Legume Processing Treatments Individually or in Combination on Their Trypsin Inhibitor and Total Phenolic Contents. *Australian Journal of Basic and Applied Sciences*. 5(5): 1310–1322.

Paramjyothi, S., & Anjali, B. (2005). Effect of soaking seed on polyphenols of chickpea, *International Chickpea and Pigeonpea Newsletter*. 12. 24–25.

Park, R., Roman, L., Falardeau, L., Albino, L., Joye, I., & Martinez, M.M. (2020). High Temperature Rotational Rheology of the Seed Flour to Predict the Texture of Canned Red Kidney Beans (*Phaseolus vulgaris*). *Foods*. 9. 1002.

Pasqualone, A., Costantini, M., Coldea, T.E., & Summo, C. (2020). Use of Legumes in Extrusion Cooking: A Review. *Foods.* 9–958.

Patil, S.S. & Kaur, C. (2018). Review Current trends in Extrusion: Development of Functional Foods and Novel Ingredients. *Food Science and Technology Research.* 24. 23–34.

Ramakrishna, V., Rani, P.J., & Rao, P.R. (2006). Anti-Nutritional Factors During Germination in Indian Bean (Dolichos lablab L.) Seeds. *World J. of Dairy & Food Sciences.* 1(1). 6–11.

Rathod, R.P., & Annapure, U.S. (2016). Effect of extrusion process on anti-nutritional factors and protein and starch digestibility of lentil splits. *LWT Food Sci. Technol.* 66. 114–123.

Rebello, C.J., Greenway, F.L., & Finley, J.W. (2014). A review of the nutritional value of legumes and their effects on obesity and its related co-morbidities. *Obes. Rev*. 15, 392–407.

Samtiya, M., Aluko, R.E., & Dhewa, T. (2020). Plant food anti-nutritional factors and their reduction strategies: An overview. Food Production, Processing and Nutrition. 2(1). 1-14.

Samtiya, M., Soni, K., Chawla, S., Poonia, A., Sehgal, S., & Dhewa, T. (2021). Key Anti-nutrients of Millet and their Reduction Strategies: An Overview. *Acta Scientific Nutritional Health*. 5(12). 68–80.

Schmelter, L., Rohm, H., & Struck, S. (2021). Gluten-free bakery products: Cookies made from different Vicia faba bean varieties. Future. *Foods*. 4. 100038.

Simons, C.W., & Hall Iii, C. (2018). Consumer acceptability of gluten-free cookies containing raw cooked and germinated pinto bean flours. *Food Science & Nutrition.* 6 (1). 77–84.

Smith, J., & Hardacre, A. (2011). Development of an extruded snack product from the legume Vicia faba minor. *Procedia Food Sci.* 1. 1573–1580.

Sun, X., He, S., Ye, Y., Cao, X., Liu, H., Wu, Z., Yue, J., Jin, R., & Sun, H. (2020). Combined effects of pH and thermal treatments on IgE-binding capacity and conformational structures of lectin from black kidney bean (*Phaseolus vulgaris* L.). *Food Chemistry,* 329. 127–183.

Xu, B., & Chang, S.K.C. (2008). Antioxidant capacity of seed coat, dehulled bean and whole black soybeans in relation to their distributions of total phenolics, phenolic acids, anthocyanins and isoflavones. *J. Of Agricultural and Food Chemistry.* 56. 8365–8373.

Yagci, S., Altan, A., & Dogan, F. (2020). Effects of extrusion processing and gum content on physicochemical, microstructural and nutritional properties of fermented chickpea-based extrudates. *LWT Food Sci. Technol.* 124.