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USE OF PEAS (*PISUM SATIVUM* L.) AND BEANS (*PHASEOLUS VULGARIS* L.) IN HIGH-MOISTURE FOOD EXTRUSION: A REVIEW

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Abstract

Demands for plant-based food in the European Union are growing especially nowadays. Pulses are common and regional; they have an excellent nutritive value but its consumption in food industry is still low. In last decades extrusion technology has become extremely popular in food development. The aim of this study was to investigate the latest findings about pea *Pisum sativum* L. and beans *Phaseolus vulgaris* L. flour suitability for high-moisture food extrusion. Monographic method was used to analyse pulse seeds chemical content, possible pre-treatment methods, functional properties, covering the latest information about high-moisture extrusion, raw materials and technical parameters used. Pulses are a good source of protein, carbohydrates, minerals and vitamins. Chemical content, functional properties of yellow peas and different varieties of beans, except grey peas are well described in scientific literature. Germination can be promising pre-treatment for pulse seeds, it increases folic acid content, water absorption capacity and reduces the amount of antinutrients. Extrusion technology increases ready product protein digestibility and induces changes in antinutrient activity. High-moisture food extrusion characterises with moisture of raw materials above 40.00% where mostly protein concentrate and isolates from pulses are used.

Key words: pulses, germination, functional properties, high-moisture extrusion.

Introduction

Pulses are edible seeds of legume plant. They are well known and grown all over the world and are used as food and feed especially nowadays (Rawal *et al*., 2019).

Pulses consumption pattern is affected by several factors such as socio-cultural, economical and historical. The consumption of legumes in Europe is about 7.50 g per capita per day, but for the comparison, in the world − about 21.00 g per day (Rawal *et al.*, 2019). Improving pulses production, consumption and usage are important for prevention of malnutrition, micronutrient deficiencies and overweight (Calles, Xipsiti, & del Castello, 2019).

Low glycaemic index characterizes pulses, they reduce blood glucose level, which is very important factor in diabetes prevention (Calles, Xipsiti, & del Castello, 2019).

Pulses are source of protein with its variation from 17.00 to 30.00%, that is two times higher than in cereals, where globulins, salt-soluble proteins (leguminous (11S) and vicilin (7S) families) make up 70.00% of total protein (Cotacallapa-Sucapuca *et al*., 2021; Djoullah *et al.*, 2015).

Peas (*Pisum Sativum L.*) and beans (*Phaseolus vulgaris L.*) are rich with essential amino acids such as leucine and lysine (Krumina-Zemture, Beitane, & Gramatina, 2016; Nosworthy *et al*., 2017).

In 2018, European Parliament accepted European strategy for the promotion of protein crops in the European Union to meet growing consumer interest especially in demands for plant-based foods (European Parliament, 2018).

Current trend in plant-based foods is meat analogues, sports foods, instant soups, breakfast cereals, bakery and dairy substitutes. Most of plant-based products are made from pea, faba bean, soy (*Glycine max*) protein powder, protein isolates and protein concentrate using food extrusion (Kołodziejczak *et al*., 2021).

In the last decade, there has been scientific interest in extrusion cooking process; it seems to be appropriate for ready-to-eat pulse and cereals-based products. Extrusion cooking is usually carried out at a temperature up to 200 °C and a pressure of 20 MPa. The degree of grinding of the raw material and the moisture content are prerequisites for the mass to move further into the heated barrel using one or two screws (Pasqualone *et al*., 2020). However, in 2014 experiments have been realised in Latvia by developing of new type beans products using single screw extruder (Strauta *et al*., 2014).

Extrusion can be low-moisture and high-moisture. The latest trend in food extrusion is high-moisture extrusion, when moisture content of raw material is more than 40.00%, and it seems to have products with better texture and with lower energy input than using extrusion cooking (Zhang *et al*., 2019).

The aim of the present review was to investigate the latest findings about peas and beans flour suitability for high-moisture food extrusion.

Materials and Methods

Monographic method was used for this study. Available literature (monographs, journals) was reviewed in the period from 1998 to 2022. The review includes articles on the cultivation and use of pulses in the production of food products in Latvia, Europe, North and South America, as well as in Asia. As key-words used: peas (*Pisum sativum L.*), beans (*Phaseolus vulgaris L.*), extrusion and antinutrients. 40 most suitable sources from Scientific databases as

Scopus, ScienceDirect, Web of Science were studied. The main aim was to summarise and compile recent findings about peas and beans chemical composition, functional properties and possibility of pulse flour blend using in high-moisture food extrusion.

Results and Discussion

Pulses chemical composition and functional properties

Chemical composition of whole pea (*Pisum sativum* L.) seeds in dry matter is as follow: protein content 16.00-30.00%, fibre 6.00-10.00%, total lipids 1.00-3.00%, resistant starch 1.00-7.00% (Santos *et al*., 2019). Whole beans (*Phaseolus vulgaris* L.*)* seed contains (in dry matter): protein 17.70-27.90%, starch 41.80-45.60%, total dietary fibre 27.20-38.20% (including insoluble dietary fibre 13.90-32.80% and soluble dietary fibre 2.90-8.30%), soluble sugars 6.29 and 9.09%, total lipids 0.70-2.70%, ash 3.80-5.70% (Los *et al*., 2018; Da Silva Fialho *et al*., 2006).

Pulse protein content can be influenced by genetics, climate, soil type and harvesting practises (Mohammed *et al.*, 2018).

In 2020, results from the study carried out in Latvia where the main goal was to gather 5-year investigation results of total protein content, amino acid profile and total lipids content in different pea varieties and to estimate their usage for food production have been published (Sterna *et al*., 2020). Results of those experiments demonstrate that the peas grown in conventional and organic systems result with different total protein content as 25.30±2.00% and 21.90±2.20% respectively (Sterna *et al.,* 2020). Whereas, the total amount of essential amino acids in peas in the conventional system shows greater variation over years and varieties, 79.60±10.20 g kg^{-1} compared to organic system 77.20±5.3 g kg^{-1} with highlights leucine, lysine, phenylalanine and valine content, 14.10 g kg^{-1}, 13.00 g kg^{-1}, 9.50 g kg^{-1} and 9.10 g kg^{-1} respectively. In this experiment extruded pea flakes were made using high-temperature short time extrusion. Results of experiments demonstrate no significant differences in nutritional value of raw and extruded pea flakes (Sterna *et al*., 2020). Krumina-Zemture, Beitane, & Gramatina, (2016) determined total amino acid content in organic pea flour (Latvia). The results showed that total amount of amino acids was 19.30 g 100 g^{-1} of which 6.89 g 100 g^{-1} were essential amino acids. Essential amino acids accounted for 35.00% from total amino acid amount. Lysine content was roughly 22.00% and 1.58 g 100 g^{-1} in absolute values.

Canadian scientists determined protein content, amino acid profile, protein digestibility-corrected amino acid score (PDCAAS), protein efficiency ratio (PER) and digestible indispensable amino acid score (DIAAS) in cooked four varieties of *Phaseolus vulgaris* (kidney, navy, pinto, black beans) and one variety of yellow peas (Nosworthy *et al*., 2017). In 1991, FAO made the lowest ratio observation model, as the reference pattern (FAO/WHO, 1991). This model was used for sulphur containing amino acids – methionine, cysteine, tryptophan evaluation. The scientist declares that amino acid score for methionine and cysteine were limiting for red kidney beans and black beans 0.70 mg g^{-1} and 0.76 mg g^{-1}, respectively. The tryptophan was limiting for navy beans, split yellow peas, and pinto beans, 0.83 mg g^{-1}, 0.73 mg g^{-1}, 0.77 mg g^{-1}, respectively. As a reference, casein is used in Canada (Nosworthy *et al*., 2017). Black beans showed the lowest results in true protein digestibility (TDP %) almost 70.00% compared with pinto beans 76.00%, navy beans 80.00%, kidney beans 79.00%, yellow peas 87.00%. The PDCAAS is protein evaluation method combining amino acid requirements of human and the ability to digest it (the maximum is 100%). The results showed the highest value observed for navy beans, 67.00%, kidney beans 55.00%, black beans 53.00%, pinto beans 59.00%, spilt peas 64.00% (Nosworthy *et al.*, 2017). It seems that navy beans and yellow peas are easier to digest but the starch content is also very important factor for pulse used in food production.

The relatively low degree of digestibility of starch in legumes is attributed to the unavailability of starch granule amylases embedded in intact cell wall structures (Dahl, Foster, & Tyler, 2012). Ferawati, Hefni, & Witthöft (2019) studied how boiling, roasting and germination affect starch in pulses. After processing, the resistant starch content was twofold higher in yellow pea flour and almost threefold higher in faba bean (*Vicia faba* variety 'Alexia') flour, but decreased by 18.00–54.00% in grey pea flour and by 80.00–90.00% in white bean flour in comparison with unprocessed pulse flour. Microscopic examination of cooked whole legumes (green, yellow peas, navy beans and pinto beans) explained that a large part of the starch was partially gelatinized and located in the walls of intact cells, while cooked flour pastas contained few gelatinized granules. After *in vitro* digestion in the upper intestine, starch was unavailable to digestive enzymes (Brummer, Kaviani, & Tosh, 2015). Studies have been conducted to the dietary intake of dried peas in patients with type 2 diabetes and the results showed that peas, as carbohydrate source in a mixed meal, cause significantly minor glycaemic and insulin reactions than potatoes (*Solanum tuberosum*) (Schäfer *et al*., 2003).

Pulse biological component are antinutritional factors. They are worthwhile as prebiotics, but at the same time, they are heat resistant, cause flatulence and inhibit absorption of trace elements as Ca, Zn, Fe (Dahl, Foster, & Taylor, 2012; Da Silva Fialho *et* *al.*, 2006). Trypsin inhibitors (class of proteins) can reduce specific amino acid availability, e.g. they can bind with lysine and arginine (Kumar *et al.*, 2021; Ramireddy & Radhakrishna, 2021).

Antinutritional factor reducing methods are germination, boiling, soaking and extrusion (Ramireddy & Radhakrishnan, 2021). High treatment temperature as 148 °C and short extrusion time, however 25.00% moisture content of raw material and 100 rpm (screw speed rotation) were the most effective circumstances for tannin, trypsin, α-amylase inhibitors reduction in peas without effecting protein content,– how it eventuate by germination, dehulling and soaking (Alonso, Orúe, & Marzo, 1998).

Pulses contain sugar complexes such as galactooligosaccharides (GO), raffinose, stachyose and verbascose. Study results showed that the GO contents varied from 3.12 to 5.71% in ten different varieties of beans in Brazil (Da Silva Fialho *et al.,* 2006). Canadian researchers have found that peas contain oligosaccharides (3.73% of total dry matter), raffinose 0.48±0.07%, stachyose 2.36±0.39% and verbascose 0.89±1.17% (Tosh *et al.*, 2013).

In Harmankaya *et al.* (2010) study, 19 genotypes of peas were investigated; obtained results showed average mineral content for potassium 757.94±1.81 mg 100 g^{-1}, for phosphorus 302.90±0.72 mg 100 g^{-1}, for magnesium 84.06±0.56 mg 100 g^{-1}, and calcium 82.53±0.37 mg 100 g^{-1}. Researchers find out a strong positive correlation between potassium and phosphorus, potassium and sulphur and zinc ($p<0.01$) (Harmankaya *et al.*, 2010). Scientists Dahl, Foster & Taylor (2012) reviewed iron content in peas 9.70 mg 100 g^{-1} selenium 4.20 mg 100 g^{-1}, zinc 4.10 mg 100 g^{-1}, molybdenum 1.20 mg 100 g^{-1}, manganese 1.10 mg 100 g^{-1} and cuprum 0.90 mg 100 g^{-1} (Dahl, Foster, & Taylor, 2012). Iron, zinc and phytate concentration in beans traditionally is in range of 38.40–93.70 µg 100 g^{-1}, 18.90–43.60 µg 100 g^{-1}, 4.80–19.90 µg 100 g^{-1}, respectively (Caproni *et al.*, 2020). The amount of trace minerals in beans varieties can be in range 10.10–109.00 µg 100 g^{-1} of zinc, 2.80–10.90 µg 100 g^{-1} of copper, 15.80–64.60 µg 100 g^{-1} of phosphorus, and 6.70–14.40 µg 100 g^{-1} of aluminium (Hayat *et al.*, 2014).

A study in Latvia shows that pea flour in comparison to wheat flour can be a good source or B group vitamins. Thiamine content in pea flour was 1.11 mg 100 g^{-1} and riboflavin 0.71 mg 100 g^{-1} (Beitane & Krumina-Zemture, 2017). Peas also contains folate within 23.70 µg 100 g^{-1} to 101.00 µg 100 g^{-1} (Dahl, Foster, & Taylor, 2012). Results from study in Sweden showed that total choline content in raw yellow pea (DM) was 136.00±4.90 mg 100 g^{-1}, grey pea (unknown Latvian variety) 141.00±4.70 mg 100 g^{-1}, but after roasting total choline content was higher in yellow and grey peas 143.00±3.50 mg 100 g^{-1} and 142.00±3.80 mg 100 g^{-1} respectively. After 48 h germination total folic acid content increased from 73.00±2.90 mg 100 g^{-1} to 254.00±11.50 mg 100 g^{-1} in yellow peas and from 90.00±0.50 mg 100 g^{-1} to 256.00±6.50 mg 100 g^{-1} in grey peas (Ferawati, Hefni, & Witthöft, 2019).

Beans are a good source of folate 0.15-0.68 mg 100 g^{-1}, thiamine 0.81-1.32 mg 100 g^{-1}, riboflavin 0.11-0.41 mg 100 g^{-1}, niacin 0.85–3.21 mg 100 g^{-1} and pyridoxine 0.30-0.66 mg 100 g^{-1} (Hayat *et al.*, 2014). In Spain, using randomized block design 255 lines of beans (*Phaseolus vulgaris*) in different colours – white, white with speckle, yellow, cream, brown, red, pink, grey and black were grown (Madrera *et al.*, 2021). All samples were analysed for phenol antioxidant index (PAOXI), which is an indicator to sum up antioxidant phenols concentration and their effectiveness. The highest PAOXI had beans in cream colour 18.90±4.20, red coloured beans 18.70±3.20, black coloured beans 18.10±2.70, brown coloured beans 17.40±3.20 and pink coloured beans 15.90±2.50 (Madrera *et al.*, 2021). In other study, researchers found out that the antiradical activity of pulse varieties closely correlated with the colour of the seed coat (Dahl, Foster, & Taylor, 2012).

Physicochemical and functional properties of pulses

In the study, the physicochemical and functional properties of raw, unshelled pulse flour were investigated. Results showed that raw beans bulk density (BD) differs between bean varieties; pinto 0.68 g mL^{-1}, lima 0.78 g mL^{-1}, small red 0.68 g mL^{-1}, red kidney 0.68 g mL^{-1}, black bean 0.54 g mL^{-1}, navy 0.69 g mL^{-1}, black eyed 0.76 g mL^{-1} and mung beans 0.80 g mL^{-1} (Du *et al.*, 2014). Water absorption capacity (WAC) in raw yellow peas was 0.80±0.03 $g_{water}\ g^{-1}_{DM}$ but in grey peas 1.10±0.04 $g_{water}\ g^{-1}_{DM}$. Raw white bean WAC was 1.20±0.02 $g_{water}\ g^{-1}_{DM}$. Boiling, roasting and germination were used as flour treatment methods. All methods increased ($p<0.001$) WAC among 1.50 and 3.00 times comparing with untreated pulses (Ferawati, Hefni, & Witthöft, 2019).

The raw materials in Ferawati, Hefni & Witthöft (2019) research were investigated on water and oil absorption capacity (OAC). It is necessary to indicate that the OAC is very important for enhancing the mouthfeel and retaining products flavour. The OACs of pinto, lima, small red, red kidney, black bean, navy, black eyed and mung beans were in scale from 0.93 g 100 g^{-1} to 1.38 g 100 g^{-1}, where the differences were statistically significant (Du *et al.*, 2014). However, soaking and boiling reduced emulsion activity (EA) in white bean flour ($p<0.001$) by 17.00% and emulsion stability (ES) by 25.00% ($p<0.001$), but did not change ($p>0.41$) the emulsion properties of grey, yellow peas and faba bean flours (Ferawati, Hefni,

& Witthöft, 2019). Scientists in China have revealed that the emulsion activity of pulse flours contrasted, small red bean flour had the highest value 92.20% and lima bean flour the lowest value 63.77%. Emulsion stability in pinto bean flour was 84.15%, but in navy bean flour 96.90%. These are the extreme minimum and maximum absolute values. Protein content, starch, lipids and sitosterols are linked with emulsion stability and emulsion activity in pulse flour. Proteins in their tertiary structure have hydrophobic polar side chains and thus impact emulsion properties and solubility (Du *et al*., 2014). The sprouting decreased ($p<0.007$) EA by 15.00-33.00% in grey pea flour and ES by 14.00-48.00% in grey pea, faba, and white bean flours, in comparison with untreated flours. Boiling and roasting influenced foaming stability (FS) in grey and yellow peas and white and faba bean, approximately in range 21.00-48.00% ($p<0.001$). Roasting and germination highlighted grey pea results in emulsion properties as the lowest ($p<0.004$) and the FS was lower ($p<0.001$) than in other tested samples. Thus, they could be used in the production of coatings for egg custard, sausages, pastries and baked goods. However, processed grey pea flour usage in sauces and meat substitutes can be restricted (Ferawati, Hefni, & Witthöft, 2019).

Viscosity is one of the most important quality factors in food products. It describes by pasting temperatures. In the study of Maninder, Sandhu, & Singh (2007) different bean flour pasting temperatures were tested. The highest results at 83.0 °C showed lima beans, the lowest at 73.2 °C mung beans. Higher treatment temperature pronounces starch more resistant to swelling and tearing. As measurement unit for viscosity, Rapid-Visco Analyser units (RVU) are used. The highest peak viscosity had black eye bean flour − 216.80 RVU, but the lowest value had small red bean 103.30 RVU (Du *et al*., 2014). Mean gelatinization temperature of field pea flour was 59 °C in onset, 66 °C on peak and 74 °C on conclusion. Peak height index was 0.68. Pasting temperature was moderate to be 73.9-75.4 °C (Maninder, Sandhu, & Singh, 2007).

Pulses in high moisture extrusion

Extrusion at high moisture level above 40.00%, is also known as 'wet extrusion'. Generally, for wet extrusion technology, twin-screw extruders (TSE) in large-capacity manufacturing enterprises are used (Akdogan, 1999).

High-moisture extrusion is a process where in combination of moisture, pressure, shear stress conditions and temperature, raw materials are forced through the heating barrel, mixed between screws, shaped, cooled and sheared. All these factors influence proteins, cause their denaturation, starch gelatinization and degradation, lipid oxidation, antinutrient, trace minerals and vitamins degradation (Zhang *et al*., 2022). The literature review shows that extrusion increases the protein digestibility *in vitro* by approximately 13.00-18.00% (Pasqualone *et al*., 2020).

Current trend in high moisture extrusion is meat analogues, usually made from pea and bean protein powders and isolates, soy protein isolates, maize (*Zea mays*) and wheat (*Triticum*) starch, microalgae, peanut (*Arachis hypogaea*) protein and isolates. Cornet *et al.,* (2021) an overview article described high moisture food extrusion process using a single screw extruder, twin extruder or shear cell. Moisture content of raw materials was 55.00-72.00% and the maximum extrusion temperature was 95-170 °C depending on nature of raw material (Cornet *et al*., 2021). In another study, certain conditions for successful high-moisture food extrusion process were mentioned. The product after processing had fibrous meat-like structure, moisture content was more than 30.00% and was ready-to-eat. Weaknesses of technology is high-cost equipment. Inflexible restrictions on raw materials were more than 60.00% of protein, moisture content was in range 40.00−80.00%. Researchers indicate problems with short time storage conditions and modification with product palatability. Most important aspect of high-moisture extrusion is the future development direction (Zhang *et al*., 2022).

Screw speed and length, moisture content, different temperatures in barrels − all these aspects can make structural and chemical changes in products, e.g. lower antinutrient activity, shorter cooking time, changes in carbohydrates concentration complex and denaturation of protein structures (Berrios, Ascheri, & Losso, 2012; Cotacallapa-Sucapuca *et al*., 2021).

Yoshimoto *et al.* (2020) studied suitability of dehulled yellow pea, unshelled yellow pea, chickpea (*Cicer arietinum*), and lentil (*Lens culinaris*) in noodles obtaining. Prepared noodles analysed with *in vitro* digestion and studied the opportunity to use them as functional staple food with an aim to control blood glucose. However, nutrition with low glycaemic index can be used as prevention for type 2 diabetes, gastrointestinal cancers and obesity. In the experiment, water was added approximately 50% to the legume flour, dough was mixed, extruded at 120 °C, and then air dried. Results showed that rapidly available glucose (RAG) in dehulled yellow pea noodles were (YP) 8.34±1.07% and unshelled yellow pea noodles (YP-U) 8.20±0.88% it was less than both control samples commercial gluten-free pastas (made from steamed rice) 9.91±1.56% and 9.71±1.42% respectively, but there was no significant difference. In sensory evaluation (9-point scale), the highest overall acceptance had YP noodles 5.30±1.32 and, also, they had highest result in appearance, taste, aroma and stickiness 6.23±1.07, 5.60±1.25, 4.70±1.39 and 5.67±1.40, respectively. Sensory evaluation results were statistically significant. Results from physical properties tests such as breaking stress, breaking strain and bulk density showed that dehulled yellow pea noodles and unshelled yellow pea noodles were the hardest and panellist must use more force to chew noodle string. Experiments showed that noodles obtained from yellow peas are possible to use as novel staple food with the glycaemic control function, but the physical properties must be advanced (Yoshimoto *et al*., 2020).

In scientific literature, the main research data is available regarding to soy protein isolate extrusion at ~56.00% moisture using twin screw extruder or yellow pea protein isolate/concentrate at moisture content in range 66.00-70.00% using co-rotating twin screw extruder or both combinations at moisture content 50.00-70.00% (Ferawati *et al*., 2021; Maung & Ryu, 2020; Wittek, Karbstein, & Emin, 2021).

Conclusions

Pulse flour is practically not used in the high-moisture food extrusion. Peas and beans protein powders and isolates are most often used as raw materials due to their protein content more than 60% and hydrophilic nature.

Raw navy beans, black beans, small red beans can be used in high-moisture extrusion; they had lower bulk density comparing with other bean samples. Significantly higher oil absorption capacity (OAC) had raw black bean flour comparing with other bean samples. Data in literature shows that pulses with higher OAC contain more available non-polar side chains in their protein molecules.

Roasting and germination reduce foaming capacity in yellow pea flour. Boling and roasting reduce foaming stability in grey pea flour. Water absorption capacity and emulsion activity can be increased by germination, it can be used as pre-treatment method before extrusion process to solve problems with end-product palatability and hardness.

Results from experiments with yellow peas flour high-moisture extrusion with 50% moisture content using twin screw extruder seem promising in pasta obtaining.

Further research is needed to clarify the possibilities of peas and beans flour blend in high moisture extrusion.

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