Investigation of the combination of legumes and cereals in the development of extrudate snacks and its effect on physico-chemical properties and in vitro starch digestion

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Summary

The application of different levels of legumes in development of cereal-based extrudates has potential to produce healthy snack foods. The aim of this study was to investigate the effect of addition of legumes such as yellow pea, green pea, lentils and chickpea to wheat-, rice-, barley- and maize-based extrudates on its physical and nutritional properties. While legume fortification reduced the water absorption index (*WAI*) of barley-based extrudates, *WAI* was unaffected for wheat- and maize-based extrudates. On the contrary, type of legume influenced the water solubility index (*WSI*) of maize- and wheat-based extrudates. The results showed significant variation in final viscosity of the extrudates according to the levels of legume addition and cereal type. Particularly, in barley-based extrudates the final viscosity showed increase with addition of legume levels. However, the area under the curve (*AUC*) values for reducing sugars was reduced in legume-added samples compared to the control samples, the strongest decrease ($p < 0.05$) being observed in wheat + 5 % chickpea sample. The observed difference in viscosities shows possibilities of modification in physical properties and decreasing trend in *AUC* suggests the possibility for the production of low glycaemic extrudates through legume fortification.

Keywords

extrusion; starch; glycaemic response; legumes

Processed foods are currently a popular choice for consumers in terms of convenience and accessibility. The abundance and availability of different varieties as well as ease of use, preparation and storage make processed foods particularly popular in urban society [1]. Socio-economic changes, such as increasing industrialization and fast-changing life styles, are responsible for changing the dietary habits of consumers [2, 3]. Among these processed products, ready-to-eat (RTE) products are gaining consumers' attention due to their accessibility and convenience; they are also affordable to the consumer. Cereal grains are an important constituent of RTE product market and, in many countries, these cereal-rich diets are the primary source of nutrition. Cereals themselves are rich in carbohydrates, constituting the main source of carbohydrates in our diet, with around 50 % of cereal production in the world utilized for human consumption [2]. Products such as wheat, maize and barley also contain a considerable amount of protein and dietary fibre and are also the main source of energy (56 %) for humans in some parts of the world [4–6].

Due to low availability or ethical reasons, some of the world's population are unable to access meat and milk for nutrients and the nutrition of these populations could be ensured through consumption of legume-fortified cereal based snacks [7]. Researchers have identified nutritional improvements in traditional cereal-based products such as biscuits and pasta to which legumes have been added [8–10]. Legumes such as lentils, peas and beans are a rich source of protein and can replace cereal components in cereal-based snack foods [11–15]. In recent years, there has been a particular attention to the use of dietary fibre in the reduction of glucose metabolism in type 2 dia-

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betes patients by reducing the starch breakdown and glucose absorption rate from food; the steady breakdown of carbohydrates reduces the presence of excess glucose in human blood [16, 17]. This has led to a number of researchers to investigate the potential nutritional effects of dietary fibre in conventional food products [18–20]. Intake of whole grains has previously been related to reduction in health problems such as cardiovascular diseases, diabetes and cancer, as well as in regulating digestion and obesity [6].

Most snack foods are made from refined cereal flours rich in sugars, salts, saturated fats and easily digested carbohydrates with a high glycaemic index. Excessive consumption of such foods is associated with high calorie intake, which may lead to health problems such as high blood cholesterol, type 2 diabetes, obesity and cardiovascular diseases [21–23]. Maintaining health through nutrition is therefore becoming an extensively discussed topic. Growing consumer awareness of healthy food habits has increased the pressure on food researchers to develop novel RTE products that are nutritionally rich, easy to consume and affordable. This need may be addressed by the application of extrusion cooking to the development of a product utilizing whole grains [3]. Extrusion is a multi-step and multi-functional process, which alters the chemical conformation of food ingredients through thermal and mechanical energy. Extrusion processing has the potential to develop innovative food products of unique structure through the use of underutilized whole grain-based food products. In recent years, it has been utilized in the development of functional foods such as breakfast cereals, baby foods and ready-to-eat snacks.

Due to unique features, such as low operation cost and ease of application [6, 24], extrusion cooking is an economically affordable method and may even increase the nutritional digestibility and bioavailability of foods [1, 20]. Also, extrusion process has the ability to transform raw ingredients into puffed extrudates, which can be used in grain type analogue production. Production of rice analogues were previously studied by Mishra et al. [25]. Furthermore, it has been suggested that such analogues can be utilized in RTE production. The flashing off of moisture, and pressure balance at the die interface with atmospheric pressure, are core steps in extrusion process during development of RTE products. The rapid expansion and inflation of product post extruder die generates a puffed structure with the help of expanded gas cells in the product [26]. The process involves high temperatures, inflecting the cooking of the protein and starch with a combined effect of moisture and pressure. It can also change chemical reactions and the structure of food. The extrusion process cooks starch within the extruder, while reduced moisture levels may prevent the complete gelatinization of the starch [16, 17]. The extrusion process increases the availability of readily digestible starch. It has been suggested that adding legumes and dietary fibre to food products may manipulate the glycaemic index of food. The use of dietary fibre in food production changes the food structure and reduces starch degradation [16, 17, 21] and has an impact of non-starch polysaccharides such as guar gum and wheat bran in the preparation of extruded breakfast cereals [17].

In this research, cereals-based (wheat-, rice-, maize- and barley-based) extrudates were developed using various combinations of legumes (yellow peas, green peas, chickpeas and lentils). The study aimed to determine the possibility of producing highly functional foods using legume blends in cereal-based snacks and to investigate the physico-chemical properties of the samples and starch hydrolysis in them.

MATERIAL AND METHODS

Materials

Wheat grain was obtained from Champion Flour Mills (Christchurch, New Zealand). Lentil, yellow pea, green pea and chickpea pulses were obtained from a local supermarket supplier (Foodstuffs NZ, Christchurch, New Zealand). Analytical grade chemicals were used in all experiments.

Extrusion

Whole grains of different legumes (as shown in Tab. 1) were used at 0 %, 5 %, 10 % and 15 % (on weight basis) replacement levels for wheat grain in the production of extrudates. Extrusion was conducted in a single-screw extruder through a 3 mm die face (Millbank, Auckland, New Zealand) and collected as collets. Extrusion parameters of screw speed (4.17 Hz), temperature in the barrel (180 °C) and moisture content of samples (12 %) were kept constant for all samples during the extrusion process. The screw diameter was 3 mm and L/D (length to diameter) ratio of the extruder was 10. Prior to extrusion, the feed rate was calibrated for each of the samples dry mixture using the feed hopper. The data obtained from actual mass passing through the hopper for a specific time with different speeds was used for the feed rate calibration. An automated product cutter

Tab. 1. Moisture content of extruded snack products based on different cereals.

Added legume	Replacement [%]	Moisture [g·kg-1]			
		Maize	Wheat	Rice	Barley
None (control)	0	86.7 ± 0.7 ab	74.3 ± 1.9 bcd	85.9 ± 1.9 a	66.7 ± 0.1 g
Lentil	5	80.9 ± 0.4 ef	73.2 ± 0.4 bcde	81.2 ± 1.0 abcd	79.6 ± 0.3 a
	10	82.4 ± 0.1 de	72.3 ± 0.9 cde	80.8 ± 1.1 abcd	78.9 ± 1.2 ab
	15	81.0 ± 1.0 ef	73.1 ± 0.7 bcde	82.0 ± 1.9 abc	77.2 ± 0.2 bcd
Green pea	5	87.8 ± 0.6 ab	72.1 ± 0.1 cde	75.7 ± 1.4 d	78.5 ± 0.1 abc
	10	81.8 ± 0.0 e	76.0 ± 0.5 abc	85.0 ± 0.2 a	77.6 ± 0.1 bcd
	15	82.5 ± 0.3 cde	75.3 ± 0.6 abc	86.5 ± 1.0 a	77.1 ± 0.6 cd
Yellow pea	5	84.9 ± 0.3 bcd	69.3 ± 1.5 e	77.9 ± 1.6 bcd	70.6 ± 0.2 f
	10	85.0 ± 0.5 bc	55.7 ± 0.4 f	76.3 ± 2.3 cd	78.5 ± 0.1 abc
	15	82.9 ± 0.2 cde	69.8 ± 1.8 de	76.2 ± 1.7 cd	78.2 ± 0.8 abc
Chickpea	5	78.8 ± 0.9 f	77.2 ± 1.7 ab	81.8 ± 1.6 abc	73.8 ± 0.1 e
	10	75.1 ± 0.5 g	75.5 ± 1.4 abc	83.0 ± 0.2 ab	76.1 ± 0.2 d
	15	76.1 ± 0.1 g	79.2 ± 0.1 a		

Values are expressed as mean ± standard deviation. Values within a column followed by the same superscript letter are not significantly different from each other ($p > 0.05$).

was mounted to the die face. The cutter was set at the same speed as the shaft screw speed to obtain a pelleted product. The final warm expanded products were collected and allowed to dry and cool down to ambient temperature for half an hour, they were then sealed in polyethylene bags for storage.

Total starch

Total starch analysis was carried out in triplicate according to the official AACC method 76.13 [18].

In vitro starch digestion

In vitro starch digestion of the extruded samples was analysed by using uniform sizes of extruded samples as of our previous method [23]. Pepsin and amyloglucosidase were obtained from Sigma-Aldrich (St. Louis, Missouri, USA). Briefly, a sample containing 0.25 g starch was weighed into a digestion pot. Then, 30 ml of water was added and the temperature brought to 37 °C with constant stirring. Stomach digestion was mimicked by adding 0.8 ml HCl and 1 ml 10% pepsin solution in 0.05 mol·l^{-1} HCl with continued stirring, while maintaining the temperature at 37 °C for 30 min. Stomach digestion was halted by the addition of 2 ml $NaHCO_3$. Small intestine digestion was mimicked by the addition of 5 ml 0.1 mol·l^{-1} Na maleate buffer pH 6 and 5 ml 2.5% pancreatin in 0.1 mol·l^{-1} Na maleate buffer pH 6. The volume was then made up to 53 ml (using reverse osmosis water) under continued stirring and incubated at 37 °C for 120 min. Amyloglucosidase (0.1 ml) was added to prevent end product inhibition. Aliquots (1 ml) were taken at 0, 20, 60 and 120 min and placed into ethanol to halt digestion.

These samples were then analysed for their reducing sugar content using 3,5-dinitrosalicylic acid analysis [23]. Ten grams of 3,5-dinitrosalicylic acid were dissolved in 400 ml, 2 mol·l^{-1} NaOH with warming and vigorous stirring, while 300 g sodium potassium tartrate tetrahydrate was dissolved in 500 ml distilled water. The two solutions were mixed together and made to 1 l with reverse osmosis water to create dinitrosalicylic reagent. Acetate buffer, 0.1 mol·l^{-1}, pH 5.2, was made by dissolving sodium acetate trihydrate in 10 ml distilled water. This was adjusted to pH 5.2 with acetic acid, 4 ml 1 mol·l^{-1} $CaCl_2·2H_2O$ were added and then it was made to 1 l. Enzyme mixture A was made using amyloglucosidase (EC 3.2.1.3. from *A.niger* (Megazyme, Bray, Ireland; E-AMGDF) and invertase (EC 3.2.1.26 from yeast; Megazyme, E-INVRT) both 1 % in 0.1 mol·l^{-1} acetate buffer pH 5.2.

An aliquot of 0.05 ml of each sample in ethanol was placed in a tube with 0.25 ml enzyme solution A. A sample blank consisted of 0.05 ml of reverse osmosis water. The tubes were agitated to mix the aliquot and enzyme, then allowed to stand for 10 min at room temperature. Then, 0.75 ml dinitrosalicylic mixture (0.5 mg glucose, 4 mol·l^{-1} NaOH and dinitrosalicylic reagent mixed in ratio 1 : 1 : 5) was added to each tube. The tubes were covered with aluminium foil and heated at 95–100 °C in a boiling water bath for 15 min. Samples were then cooled and diluted with 4 ml of water before being transferred to cuvettes. absorbance was measured at a wavelength of 530 nm using a V-1200 Spectrophotometer (VWR, Radnor, Pennsylvania, USA).

The glycaemic response to a snack product was recorded as the area under the curve (*AUC*). Reducing sugars released during the in vitro analysis were plotted against time giving a glycaemic response curve. To be able to calculate the area between the response curve and the x axis, the graph is then divided into trapezoids. The area of each trapezoid was found using Eq. 1 known as the trapezoid rule.

$$AUC = 0.5 \times (t_2 - t_1) \times (h_1 + h_2) \qquad (1)$$

where t_2 is time in seconds at the end of the experiment, t_1 is time in seconds at onset of the experiment, h_1 is the height of the graph at the onset of the experiment and h_2 is the height of the graph at the end of the experiment. This can be summarized as:

$$AUC = \frac{1}{2} \sum_{i=0}^{n-1} (t_{i+1} - t_i)(y_i + y_{i+1}) \qquad (2)$$

where there are $n+1$ measurements y_i at times t_i ($i = 0, ..., n$). The area can be divided by the length of time the measurements were recorded over in order to standardise the values. These methods follow those reported previously [2, 19].

Analysis by Rapid Visco Analyser

A 5 g sample was weighed and added to a canister containing 25 ml of distilled water and the thermal-visco profiles of resulting pastes were measured by Rapid Visco Analyser (Perten Instruments, Hägersten, Sweden). Briefly, the canister containing distilled water and sample were heated to 95 °C and held at this temperature for 3 min before cooling to 50 °C. The peak viscosity (*PV*), final viscosity (*FV*) and breakdown (*BD*) of materials were recorded. A similar profile was described by Brennan et al [20].

Moisture content

Moisture of ground sample (1 g) was determined by oven drying overnight at 105 °C as previously described [23].

Water solubility index and water absorption index

Water solubility index (*WSI*) and water absorption index (*WAI*) measurements were conducted on ground samples as follows. Approximately 1 g sample was weighed into a tared centrifuge tube and was mixed with 10 ml distilled water. The resulting slurry was vortexed for 1 min and allowed to stand for 30 min. Then it was centrifuged at 2 000 ×g for 30 min. The supernatant was decanted into a pre-weighed evaporating dish, the tube containing the pellet was re-weighed. The evaporating dish was placed in an oven at 105 °C and was evaporated to a constant weight. *WAI* is expressed as millilitres of water retained per kilogram of sample and *WSI* is the mass of dry solids in the supernatant expressed as millilitres of water retained per kilogram of the original mass of sample.

Statistical analysis

All experiments were performed in triplicate unless otherwise stated. Statistical differences in product characteristics were determined by one-way analysis of variance (ANOVA) using Minitab 16 software (Minitab, Coventry, United Kingdom) and Tukey's comparison test ($p < 0.05$). All values show comparison against the control samples.

RESULTS AND DISCUSSION

Moisture

As illustrated in Tab. 1, significant differences ($p < 0.05$) were observed in moisture levels of maize-based extrudates after addition of legumes. The highest value was observed in the sample containing 5% green pea addition (8.78 g·kg^{-1}). Moisture content of samples containing wheat or rice showed significant decrease in moisture levels after addition of yellow pea. The addition on 5% green pea reduced the moisture content (7.57 g·kg^{-1}) of rice-based extrudates, whereas the lowest value in wheat-based samples was observed in samples containing 10% yellow pea (5.57 g·kg^{-1}). Previous studies reported similar observations [2, 27, 28]. The reduction in moisture levels of samples is likely to be associated with extrusion parameters, with barrel temperature and feed moisture. Previous research reports indicated that higher extrusion temperature led to higher moisture loss from the feed, and increase in feed moisture helped in decreasing moisture loss during extrusion [4, 29]. Moisture retention during extrusion can negatively affect consumer acceptance of snack foods by altering product's physical properties such as hardness and bulk density [2]. Kasprzak et al. [30] reported that extrudates containing less moisture developed air cells with high diameters and thinner cell walls, the rupture of which under heat gave crunchiness to the product.

Effect on water solution and water absorption indices

Tab. 2 shows the *WAI* values and Tab. 3 illus-

Tab. 2. Water absorption index of extruded samples based on different cereals.

Added legume	Replacement [%]	Water absorption index [ml·kg^{-1}]			
		Maize	Wheat	Rice	Barley
None (control)	0	3.90 ± 0.17 ^{ab}	4.39 ± 0.06 ^{a}	3.84 ± 0.09 ^{c}	6.03 ± 0.23 ^{a}
Lentil	5	4.15 ± 0.13 ^{ab}	4.39 ± 0.04 ^{a}	4.26 ± 0.16 ^{ab}	5.20 ± 0.20 ^{b}
	10	4.13 ± 0.01 ^{ab}	4.40 ± 0.09 ^{a}	4.20 ± 0.05 ^{ab}	5.18 ± 0.17 ^{b}
	15	4.14 ± 0.25 ^{ab}	4.39 ± 0.06 ^{a}	4.40 ± 0.08 ^{a}	5.16 ± 0.15 ^{b}
Green pea	5	3.92 ± 0.19 ^{ab}	4.40 ± 0.12 ^{a}	4.05 ± 0.11 ^{bc}	5.30 ± 0.06 ^{b}
	10	3.73 ± 0.22 ^{b}	4.24 ± 0.09 ^{a}	3.99 ± 0.14 ^{bc}	5.08 ± 0.10 ^{b}
	15	4.00 ± 0.04 ^{ab}	4.36 ± 0.02 ^{a}	4.05 ± 0.13 ^{bc}	5.08 ± 0.48 ^{b}
Yellow pea	5	3.76 ± 0.21 ^{b}	4.42 ± 0.08 ^{a}	3.97 ± 0.05 ^{bc}	5.24 ± 0.10 ^{b}
	10	3.77 ± 0.11 ^{b}	4.37 ± 0.16 ^{a}	3.98 ± 0.18 ^{bc}	5.36 ± 0.21 ^{b}
	15	4.05 ± 0.15 ^{ab}	4.21 ± 0.14 ^{a}	4.18 ± 0.05 ^{abc}	5.04 ± 0.13 ^{b}
Chickpea	5	3.95 ± 0.01 ^{ab}	4.47 ± 0.07 ^{a}	4.10 ± 0.14 ^{abc}	5.40 ± 0.14 ^{b}
	10	4.35 ± 0.24 ^{a}	4.35 ± 0.15 ^{a}	4.26 ± 0.12 ^{ab}	5.05 ± 0.16 ^{b}
	15	4.25 ± 0.10 ^{a}	4.17 ± 0.14 ^{a}	3.84 ± 0.09 ^{c}	6.03 ± 0.23 ^{a}

Values are expressed as mean ± standard deviation. Values within a column followed by the same superscript letter are not significantly different from each other ($p > 0.05$).

Tab. 3. Water solubility index values for extruded samples based on different cereals.

Added legume	Replacement [%]	Water solubility index [ml·kg^{-1}]			
		Maize	Wheat	Rice	Barley
None (control)	0	25.79 ± 3.04 ^{cd}	22.77 ± 0.43 ^{bc}	24.67 ± 2.82 ^{a}	21.38 ± 1.02 ^{a}
Lentil	5	34.30 ± 2.02 ^{a}	18.83 ± 0.29 ^{e}	28.21 ± 1.40 ^{a}	15.74 ± 0.49 ^{b}
	10	30.78 ± 1.93 ^{abc}	19.45 ± 0.14 ^{de}	24.53 ± 1.97 ^{a}	17.53 ± 0.95 ^{ab}
	15	32.64 ± 2.46 ^{ab}	20.65 ± 1.61 ^{cde}	24.57 ± 1.64 ^{a}	16.86 ± 1.75 ^{b}
Green pea	5	30.39 ± 1.21 ^{abc}	22.07 ± 0.25 ^{cd}	27.32 ± 1.72 ^{a}	19.57 ± 0.52 ^{ab}
	10	31.05 ± 2.92 ^{abc}	19.01 ± 0.30 ^{e}	27.52 ± 1.50 ^{a}	16.26 ± 1.24 ^{b}
	15	22.71 ± 2.82 ^{d}	20.59 ± 1.22 ^{cde}	26.20 ± 1.13 ^{a}	16.71 ± 2.18 ^{b}
Yellow pea	5	29.77 ± 2.30 ^{abc}	25.04 ± 1.41 ^{b}	24.76 ± 0.39 ^{a}	19.21 ± 1.69 ^{ab}
	10	28.26 ± 3.43 ^{abcd}	29.53 ± 0.32 ^{a}	28.04 ± 0.62 ^{a}	17.59 ± 1.70 ^{ab}
	15	29.11 ± 2.02 ^{abcd}	28.60 ± 0.33 ^{a}	26.92 ± 1.77 ^{a}	18.62 ± 0.82 ^{ab}
Chickpea	5	32.24 ± 1.85 ^{abc}	20.65 ± 1.91 ^{cde}	27.09 ± 1.23 ^{a}	18.93 ± 1.76 ^{ab}
	10	26.46 ± 0.84 ^{bcd}	20.45 ± 1.09 ^{cde}	27.50 ± 0.78 ^{a}	17.55 ± 2.57 ^{ab}
	15	30.11 ± 0.90 ^{abc}	20.35 ± 0.15 ^{cde}	24.67 ± 2.82 ^{a}	21.38 ± 1.02 ^{a}

Values are expressed as mean ± standard deviation. Values within a column followed by the same superscript letter are not significantly different from each other ($p > 0.05$).

trates the *WSI* values of the extrudates. Substitution of cereals with legumes did not significantly ($p < 0.05$) affect *WAI* of samples containing maize and wheat. Both the samples containing barley and rice showed significant variation ($p < 0.05$) in *WAI* after inclusion of legumes. The rice-containing samples with 15% lentil addition presented a value of 4.40 ml·kg^{-1}, whereas the barley-containing samples with 15% yellow pea showed a value of 5.04 ml·kg^{-1}. *WSI* of samples containing rice did not show significant change after legume addition. However, there was a significant ($p < 0.05$) variation in maize-, barley- and wheat-based extrudates compared to control products. Inclusion of 10% and 15% yellow pea significantly ($p < 0.05$) increased *WSI* of samples containing wheat compared to control sample. Substitution by legumes negatively affected *WSI* of samples containing barley, with significantly ($p < 0.05$) lower *WSI* values recorded in legume-added samples containing barley compared to control sample. Sharma and Gujral [31] reported that changes in *WAI* and

WSI of extrudates depend on extrusion temperature, cultivar and feed moisture. A possible reason for this observation could be that the feed moisture rate during extrusion might restrict starch gelatinization during extrusion process and this mechanism led to low *WAI* of samples containing barley [31, 32]. The higher moisture content in samples containing rice might increase gelatinization and it further led to higher *WAI*.

Pasting properties

The pasting properties of cereal-based extrudate samples are shown in Tab. 4, 5, 6. No significant variations were observed in *PV* (Tab. 4) and *BD* (Tab. 5) of samples containing maize, barley or rice after legume addition. Substitution by legumes altered *FV* (Tab. 6) of the extrudates. For instance, *FV* of samples containing maize with 5% green pea addition showed a significant decrease compared to the maize control sample, whereas samples containing maize with 15% green pea addition showed higher *FV* compared to the control maize sample. Substitution by legumes significantly ($p < 0.05$) increased *FV* of barley-based samples. The highest increase in *FV* was observed in samples containing barley with 10% yellow pea. Significant ($p < 0.05$) decrease was observed in *FV* of rice-based extrudates after adding legumes. Variation was observed in *FV* of wheat-based samples. Wheat samples with 10% green pea addition showed an increase in *FV*, whereas a reduction in *FV* was observed in wheat samples with yellow pea addition. The variation in *FV* of wheat-based extrudates was explained by BALASUBRAMANIAN et al. [33], who reported that legume-fortified cereal-based extrudate products developed a complex formation of starches that led to low *PV* and *BD*. However, higher *FV* values were observed in wheat-based samples than in control samples, which corroborate with the present study. Also, our findings showed that an increase in legume addition to barley-based extrudates increased *FV* of the final product. SHARMA and GUJRAL [31] reported that pasting properties of barley may vary according to cultivar. Furthermore, a high content of non-starch polysaccharides, such as β-glucan, may affect the pasting properties of barley-based extrudates. SHARMA et al. [32] also observed a positive correlation between final viscosity and total β-glucan content of barley samples.

In this study, maize- and rice-based extrudates showed a slight variation in viscosity after the addition of a legume. This was likely associated with starch gelatinization, disruption to shear and temperature [26]. The addition of legume (fibre) to cereal-based products was reported to tend to reduce the viscosity of extrudates [20, 21, 33–35]. However, this effect on viscosity does not follow for rice- and maize-based extrudates. The correlation between the inclusion of non-starch polysaccharides and pasting properties of starch-based products has been discussed previously. Insufficient amount of resistant starch and fibre may be responsible for the variation in *BD*, *PV* and *FV* of these samples [21, 26].

Tab. 4. Peak viscosity values from the pasting profile of the extruded samples based on different cereals.

Added legume	Replacement [%]	Peak viscosity [mPa·s]			
		Maize	Wheat	Rice	Barley
None (control)	0	92.63 ± 2.94 ^{abc}	194.17 ± 4.40 ^{abcd}	137.33 ± 4.68 ^{a}	204.87 ± 1.65 ^{ab}
Lentil	5	94.40 ± 4.45 ^{abc}	197.86 ± 2.20 ^{abcd}	151.56 ± 4.25 ^{a}	234.70 ± 1.01 ^{ab}
	10	99.43 ± 3.10 ^{abc}	198.76 ± 2.31 ^{abc}	131.83 ± 1.09 ^{a}	196.66 ± 1.33 ^{b}
	15	84.97 ± 4.45 ^{abc}	200.20 ± 6.66 ^{abc}	131.77 ± 1.13 ^{a}	231.97 ± 2.51 ^{ab}
Green pea	5	79.47 ± 2.15 ^{bc}	207.91 ± 3.00 ^{ab}	138.63 ± 1.08 ^{a}	234.30 ± 1.70 ^{ab}
	10	90.37 ± 8.09 ^{abc}	227.47 ± 1.20 ^{a}	136.47 ± 7.51 ^{a}	238.57 ± 2.92 ^{ab}
	15	104.30 ± 3.50 ^{a}	194.64 ± 9.92 ^{abcd}	145.43 ± 3.96 ^{a}	206.90 ± 9.50 ^{ab}
Yellow pea	5	88.33 ± 1.85 ^{abc}	166.29 ± 1.2 ^{cde}	141.36 ± 7.96 ^{a}	242.60 ± 2.51 ^{a}
	10	81.43 ± 4.71 ^{bc}	149.20 ± 1.8 ^{e}	146.20 ± 3.30 ^{a}	215.13 ± 2.05 ^{ab}
	15	100.00 ± 7.56 ^{ab}	158.27 ± 1.50 ^{de}	141.10 ± 4.00 ^{a}	217.10 ± 1.07 ^{ab}
Chickpea	5	78.90 ± 3.60 ^{c}	178.03 ± 1.72 ^{bcde}	133.17 ± 6.16 ^{a}	198.13 ± 7.47 ^{b}
	10	97.77 ± 5.71 ^{abc}	174.27 ± 7.82 ^{bcde}	138.50 ± 9.26 ^{a}	233.10 ± 7.45 ^{ab}
	15	90.13 ± 4.87 ^{abc}	171.50 ± 5.81 ^{bcde}	137.33 ± 4.68 ^{a}	204.87 ± 1.65 ^{ab}

Values are expressed as mean ± standard deviation. Values within a column followed by the same superscript letter are not significantly different from each other ($p > 0.05$).

Predicted glycaemic response as reported by area under the curve values.

The starch digestibility and predictive glycaemic response of cereal-based extrudates was determined by an in vitro enzymatic starch digestion, mimicking the human digestive system. The values for reducing sugar during in vitro digestion varied according to cereal and the addition of different legume material to it (Tab. 7). A clear reduction in *AUC* indicating lower release of reducing sugars of maize- and wheat-based extrudates was observed as a result of various (5%, 10% and 15%) amount of green pea, yellow pea or chick pea addition (Tab. 7), while in the case of barley-based extrudates, legumes such as yellow pea (5–15%) and chick pea (5%) gave *AUC* values higher than the control. Tab. 7 illustrates the effect of addition of various legumes to cereal-based extrudates on standardized *AUC* values. A clear reduction in *AUC* reducing sugars of maize- and wheat-based extrudates was observed as a result of various (5%, 10% and 15%) amount of green pea, yellow

Tab. 5. Breakdown values from the pasting profile of the extruded samples based on different cereals.

Added legume	Replacement [%]	Breakdown value [mPa·s]			
		Maize	Wheat	Rice	Barley
None (control)	0	73.77 ± 2.89 ab	147.07 ± 5.67 abc	112.97 ± 3.69 a	154.03 ± 3.77 ab
Lentil	5	77.36 ± 4.11 ab	152.47 ± 2.13 abc	131.13 ± 3.95 a	178.73 ± 9.28 ab
	10	81.77 ± 2.70 ab	155.00 ± 2.11 abc	112.57 ± 1.04 a	139.73 ± 1.20 b
	15	70.17 ± 3.55 ab	157.27 ± 5.95 ab	112.37 ± 1.17 a	171.53 ± 2.10 ab
Green pea	5	64.97 ± 2.58 b	166.80 ± 3.30 a	115.60 ± 1.12 a	173.53 ± 1.99 ab
	10	75.07 ± 7.53 ab	166.53 ± 1.01 a	115.40 ± 8.25 a	185.40 ± 2.91 a
	15	85.53 ± 3.30 a	150.83 ± 7.51 abc	125.26 ± 4.29 a	154.07 ± 8.92 ab
Yellow pea	5	74.00 ± 1.85 ab	130.27 ± 4.93 abc	115.57 ± 8.91 a	180.50 ± 2.00 a
	10	67.83 ± 4.31 ab	120.10 ± 1.86 c	122.50 ± 2.60 a	158.03 ± 2.25 ab
	15	82.30 ± 6.07 ab	125.23 ± 1.39 bc	119.80 ± 4.30 a	165.17 ± 9.50 ab
Chickpea	5	65.70 ± 3.70 ab	139.40 ± 1.67 abc	115.80 ± 6.40 a	149.13 ± 8.94 ab
	10	81.57 ± 6.28 ab	124.73 ± 1.34 bc	122.36 ± 8.21 a	178.00 ± 6.48 ab
	15	75.20 ± 4.03 ab	132.20 ± 5.91 abc	112.97 ± 3.69 a	154.03 ± 3.77 ab

Values are expressed as mean ± standard deviation. Values within a column followed by the same superscript letter are not significantly different from each other ($p > 0.05$).

Tab. 6. Final viscosity values from the pasting profile of the extruded samples based on different cereals.

Added legume	Replacement [%]	Final viscosity [mPa·s]			
		Maize	Wheat	Rice	Barley
None (control)	0	161.83 ± 1.42 bcd	227.30 ± 4.91 cd	66.40 ± 2.51 a	183.23 ± 1.50 e
Lentil	5	165.60.0 ± 1.50 bc	211.13 ± 8.75 cdef	57.03 ± 3.51 de	224.00 ± 1.75 cd
	10	167.97 ± 4.66 b	215.80 ± 8.94 cde	53.46 ± 5.86 ef	20.80 ± 3.06 cde
	15	139.20 ± 7.62 e	240.90 ± 2.10 bc	52.87 ± 5.03 fg	227.43 ± 6.25 cd
Green pea	5	146.77 ± 2.51 de	235.15 ± 2.85 cd	62.60 ± 1.68 bc	231.00 ± 2.49 bcd
	10	152.57 ± 2.19 bcde	298.23 ± 2.55 a	60.13 ± 1.80 cd	231.63 ± 1.15 bcd
	15	200.80 ± 3.77 a	274.00 ± 1.25 ab	56.70 ± 3.61 de	236.20 ± 8.50 abc
Yellow pea	5	148.27 ± 2.59 de	189.23 ± 3.34 ef	68.90 ± 1.90 a	228.50 ± 3.48 bcd
	10	148.70 ± 2.08 cde	177.27 ± 7.25 f	65.20 ± 1.25 ab	273.10 ± 1.10 a
	15	187.93 ± 1.54 a	214.87 ± 3.78 cde	57.03 ± 3.51 de	243.97 ± 4.56 abc
Chickpea	5	121.35 ± 1.50 f	203.30 ± 3.41 def	50.53 ± 6.11 fg	196.63 ± 2.24 de
	10	139.63 ± 1.83 e	224.70 ± 7.67 cde	50.98 ± 8.33 g	265.60 ± 5.80 ab
	15	137.67 ± 8.11 ef	243.00 ± 3.25 bc	66.40 ± 2.5 a	183.23 ± 14.96 e

Values are expressed as mean ± standard deviation. Values within a column followed by the same superscript letter are not significantly different from each other ($p > 0.05$).

Tab. 7. Standardized area under the curve values of extruded samples following in vitro digestion.

Added legume	Replacement [%]	Standardized area under the curve values [mg·min^{-1}]			
		Maize	Wheat	Rice	Barley
None (control)	0	402.4 ± 5.3 ^{ab}	423.1 ± 7.0 ^{a}	409.8 ± 2.7 ^{ef}	348.5 ± 5.5 ^{bcd}
Lentil	5	407.3 ± 6.4 ^{a}	431.4 ± 16.9 ^{a}	412.9 ± 8.4 ^{def}	333.9 ± 2.5 ^{de}
	10	406.1 ± 13.8 ^{a}	422.4 ± 5.5 ^{a}	386.4 ± 15.9 ^{g}	333.6 ± 9.0 ^{de}
	15	396.2 ± 12.6 ^{abc}	430.9 ± 4.1 ^{a}	375.9 ± 9.6 ^{g}	332.5 ± 4.9 ^{de}
Green pea	5	348.2 ± 9.1 ^{e}	313.8 ± 8.1 ^{d}	435.9 ± 4.3 ^{bc}	348.2 ± 14.6 ^{bcd}
	10	376.1 ± 19.9 ^{bcd}	316.5 ± 3.4 ^{d}	431.7 ± 1.7 ^{bcd}	345.9 ± 3.3 ^{bcde}
	15	375.8 ± 3.7 ^{bcd}	329.1 ± 5.1 ^{cd}	383.3 ± 7.0 ^{g}	340.6 ± 4.3 ^{cde}
Yellow pea	5	393.5 ± 3.4 ^{abc}	342.3 ± 4.4 ^{bc}	463.6 ± 5.3 ^{a}	360.7 ± 6.7 ^{abc}
	10	400.2 ± 7.4 ^{abc}	357.3 ± 9.2 ^{b}	443.5 ± 5.5 ^{abc}	365.2 ± 7.4 ^{ab}
	15	397.1 ± 8.6 ^{abc}	355.5 ± 6.5 ^{b}	451.4 ± 5.5 ^{ab}	376.7 ± 10.7 ^{a}
Chickpea	5	373.1 ± 3.9 ^{cde}	326.3 ± 5.8 ^{cd}	423.8 ± 6.5 ^{cde}	362.4 ± 2.3 ^{ab}
	10	352.9 ± 1.1 ^{de}	317.8 ± 4.2 ^{d}	397.2 ± 2.4 ^{fg}	326.6 ± 6.4 ^{e}
	15	383.9 ± 4.9 ^{abc}	343.9 ± 6.4 ^{bc}	409.8 ± 2.7 ^{ef}	348.5 ± 5.5 ^{bcd}

Standardized area under the curve values of glucose produced per gram of food are given. Values are expressed as mean ± standard deviation. Values within a column followed by the same superscript letter are not significantly different from each other ($p > 0.05$).

pea or chick pea addition. The strongest decrease was observed for samples containing wheat and maize with 5% green pea addition. However, the addition of lentil grains did not significantly alter the *AUC* values of wheat- and maize-based extrudates, although lower *AUC* was obtained for rice-based extrudates with 10% and 15% lentil fortification. It was previously reported that legumes contain considerable amounts of resistant and slowly-digestible starch, resulting in lower digestibility of legume starches compared to cereal starches [36, 37]. The presence of slowly-digestible and resistant starch in legumes may increase the dietary fibre content of foods containing legumes [12]. Pastor-Cavada et al. [38] clearly observed significant increase in fibre content after legume flour was added to whole maize- and brown rice-based extrudates. This was possibly due to the fact that extrusion process tends to increase in vitro starch content and depolymerize the starch in the product at high extrusion temperatures. The process also contributes to rapid starch digestion and increases in the glycaemic response [1]. Alonso et al. [39] observed an increase in in vitro starch digestion due to a reduction in α-amylase inhibitors such as tannins, polyphenols and phytic acid. However, Brennan et al. [34] reported that manipulating product composition can be useful for increasing levels of slowly-digestible starch in a product. It was suggested that dietary fibre may coat the starch granules of a cereal-based product, inhibiting enzyme penetration during starch digestion. Furthermore, the viscous nature of fibre may affect enzyme functionality in starch degradation and hence reduce *AUC* [16, 17, 20].

CONCLUSION

Addition of various quantities of legumes to cereal-based extrudates led to significant differences in physical and nutritional properties of the products. Production of combined legume-and-cereal extrudates with low moisture (less than 9%) and low glucose response could be achieved. It was observed that combined effect of legume addition, non-starch polysaccharides, fibre content, extrusion temperature and shear stress could affect the pasting and physico-chemical properties of the product. Reduction in *AUC* sugar response could also be achieved by legume addition. It was concluded that legume fortification in cereal products for making extruded snacks has the potential to increase the nutritional quality, simultaneously decreasing its glycaemic nature.

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