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Development and Characterization of Extruded Broken Rice and Lupine (*Lupinus albus*)

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Abstract

Mixtures of cereals and legumes result in products with higher content of high biological value proteins. The thermoplastic extrusion promotes the transformation of chemical, physical and nutritional characteristics of the food such as starch gelatinization and promotes the inactivation of anti-nutritional compounds and enzymes. This study aimed to develop products extruded using broken rice and lupine and to evaluate the physical and chemical characteristics of those products. The expansion index (EI), water solubility (WSI), water absorption (WAI), texture and color were determined for the extruded rice, and Scanning Electron Microscopy (SEM) of the extruded rice was also performed. As the rice concentration in the mixture increased, the EI, WSI and WAI values as well as the a* color parameter were increased too, and the brightness was reduced. An increase in the levels of essential amino acids with the addition of lupine grain to the extrudates was observed. SEM analysis identified intact loose starch granules or pellets in the raw materials, and the extruded samples showed a compact and amorphous shape without apparent starch granules. Due to the structural changes and reduced expansion rate of the extruded mixture prepared with lupine and rice grits, use of the extruded mixtures as snacks would not be suitable. However, these mixtures could be used in pre-gelatinized flour to formulate various products to increase the protein level.

Keywords

Technological White Rice, White Lupine, Thermoplastic Extrusion, Starch

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1. Introduction

Mixtures of cereals and legumes result in products with a higher content of protein with a high biological value. While legumes are deficient in sulfurous amino acids and rich in lysine, cereals are deficient in lysine and relatively rich in sulfur-containing amino acids. Therefore, cereals and legumes are considered complementary offering advantages in the nutritional quality [1].

Rice is a cereal rich in starch that feeds more than half of the world's human population. It is the third largest cereal crop in the world, surpassed only by corn and wheat. Broken rice is a kind of rice consisting of grains broken in the milling process

Lupine (*Lupinus spp*.) has been cultivated for approximately 4000 years and is a legume that has a rich and varied nutritional composition [2]. However, lupine is not widely used in human food due to the presence of anti-nutritional factors that must be removed before consumption of this grain [3] [4].

Despite the fact that the *Lupinus albus* variety (also known as white lupine or sweet lupine) has undergone modifications over time to reduce the content of anti-nutritional factors and alkaloids, it can be perceived by the above analysis that the grain in its composition still presents alkaloids.

Application of heat is one of the main methods used to remove these anti-nutritional factors [5]-[8], and different techniques of heat application, such as extrusion, hot-air roasting, hot-air steaming, baking and microwaving, can be used [5] [7] [8].

Thermoplastic extrusion is based on heat treatment at elevated temperatures for a short duration during which the starchy and/or proteinaceous materials with expandability are coated in plastic and cooked by a combination of humidity, pressure, temperature and mechanical shearing, which promotes the chemical, physical and nutritional transformation of the food [1], such as starch gelatinization and protein denaturation. Thus, thermoplastic extrusion promotes the inactivation of anti-nutritional compounds and enzymes [9].

Among the factors that influence the nature of the extruded products are the rheological properties of the feedstock, such as moisture content, physical state and chemical composition. In particular, the amount and type of starch, protein, fat and sugars, as well as the operating conditions of the extruder, all influence the extruded products [10].

Thus, for the production of extruded foods with good quality, it is necessary to use raw materials with high starch contents to allow gelling and expansion to provide the desired physical and chemical characteristics [11]. However, lupine and other legumes, such as soybeans, have low levels of starch [9] [12], thus precluding their use in the extrusion processes as the sole raw material. Therefore, it is necessary to mix the legumes with other starchy foods, e.g., cereals, to obtain extruded products of appropriate quality [9].

Thus, this study aimed to obtain extrudates using a percentage of ground lupine (GL) to replace broken rice (BR) as well as to evaluate the physical and chemical characteristics of the raw materials and extrudates.

2. Material and Methods

2.1. Material

Polished white broken rice (BR) (donated by Crystal Ltda. located in Aparecida de Goiânia, Goiás, Brazil) and ground lupine (GL) (*Lupinus albus*), the main cultivated species in the world (provided by the Agronomic Institute of Paraná—IAPAR, grown in 2010) and were used in this study.

2.2. Methods

The analyses were divided into two steps. First (Step 1), analyses were performed with GL and BR, including granulometry, as well as scanning electron microscopy analysis. In the second step (Step 2), after extruded mixtures with different percentages of GL and BR were obtained, the expansion index (EI), water solubility index (WSI), water absorption index (WAI), texture and color of the extrudates were determined, and scanning electron microscopy was also performed on the extrudates.

2.2.1. Raw Material Granulometry

Granulometry was performed on samples of BR and GL. The set of sieves that we used included 4, 6, 9, 16 and 35 mesh (Bertel Metallurgical Industries Ltd., Caieiras, Brazil). These sieves were weighed separately and stacked in ascending order of mesh size. Then, 100 g of sample was placed under the upper sieve, and a drive agitator was used to stir (Vibratest, São Paulo, Brazil) for 10 min at maximum speed. The sieves were then weighed, and the percentage of sample retained in each was calculated by the difference in weight.

Step 2

The following three treatments were used in the extrusion process: a control with 100% BR (100BR) and mixtures composed of 90% (90BR10GL) and 80% (80BR20GL) BR with 10 and 20% GL, respectively, keeping the moisture of the uniform mixtures at 12%.

The extrudate was generated with a single screw thermoplastic extruder (Imbramaq, PQ30, Ribeirão Preto, Brazil) with the following parameters: a screw compression ratio of 3:1; a feed rate of 350 g/min; a circular die opening diameter of 4 mm; temperatures of 40˚C, 60˚C and 90˚C at the first, second and third heating zones of the extruder, respectively; and a screw speed of 250 rpm.

2.2.2. Analyses of Extruded Samples

The analyses were conducted on samples of whole and milled (flour) extrudate. Extruded flours were crushed in a Wiley mill (Tecnal, TE 020, Piracicaba, Brazil).

2.2.3. Expansion Index (EI)

The EI was calculated by the ratio of the diameter of the extruded sample determined by a digital caliper (Mitutoyo, M/P/E-103, Brazil) and the diameter of the matrix according to the methodology proposed by Fabion and Hosney (1982).

2.2.4. Water Absorption Index (WAI)

The WAI was determined according to the methodology of Anderson *et al.* (1969) [13]. Approximately 2.5 g of extruded flour and 30 ml of ultrapure water were placed in a tared centrifuge tube. The tubes were shaken for 30 min and then centrifuged at 2200 G for 10 min (Jouan, BR4i, France). The supernatant liquid was drained carefully into a tared Petri dish. The Petri dish was incubated for 1h in a water bath and subsequently placed in an oven for 3 h at 105˚C, and it was then weighed on an analytical balance (Shimadzu, AUX-220, Japan precision 10 mg - 220 g). The material remaining in the centrifuge tube was weighed, and the WAI was calculated according to Equation (1).

$$WRC = WRC/WS - WER$$

where

WRC = weight of the residue of centrifugation (g);

SW = sample weight on a dry basis (g);

WER = weight of the evaporation residue (g).

2.2.5. Water Solubility Index (WSI)

The WSI, as determined according to the methodology of Anderson *et al.* (1969) [13], was calculated as the ratio between the weight of the evaporation residue and the dry weight of the sample according to Equation (2).

$$\%ESI = WRC/WS \times 100$$

where

WER = weight of the evaporation residue (g);

SW = sample weight on a dry basis (g).

2.2.6. Determination of Hardness and Brittleness

The hardness and brittleness of the extruded samples were determined by testing the strength and compression of the samples. This analysis was performed on a texture analyzer (TA-XT2i Texture Analyzer) with a maximum load of 25 kg, and a guillotine device probe type. The following parameters were used to evaluate the samples: a pre-test speed of 3.0 mm/s, a test speed of 1.0 mm/s and a post-test speed of 5.0 mm/s.

2.2.7. Color

Colorimetric analyses were performed on raw materials (BR and GL) and the three extruded samples (100BR, 90BR10GL and 80BR20GL). A tristimulus colorimeter (Hunterlab Colorflex 45/0 Spectrophotometer, Hunter Laboratories, VA, USA) was used the standard illuminant D65 (daylight). The color measurements were based on a three-dimensional Cartesian system (xyz) represented by the CIE L^*, a^* and b^*.

2.2.8. Microscopy

The general appearance of the raw materials (BR and GL) and extrudate was assessed by scanning electron microscopy (Mev, Fed, Quanta 200FEI). The mounting of the samples was performed on supports (stubs) with double-sided adhesive tape on which the samples were fixed and covered with a thin layer of gold sputter.

2.2.9. Statistical Analysis

All experiments were performed in triplicate. We used analysis of variance (single-factor ANOVA) and Tukey's test at 5% probability to determine the significance of the results [14].

3. Results

The results of the analysis of particle size of the BR and GL samples are shown in **Table 1**. The results indicated that 97% of lupin was retained in the 16 mesh sieve, whereas 87% of the GL was retained on the 9 and 16 mesh sieves (54% in 9 mesh sieve and 33% in 16 mesh sieve). To determine the size of the samples in millimeters, it is necessary to know the size of the sieves in millimeters. The 6, 9, 16 and 35 mesh sieves are equivalent to 3.3, 2.0, 1 and 0.4 mm, respectively. Thus, 97% of the BR was between 2 and 1 mm, and 87% of the GL was between 3.3 and 1 mm (54% between 3.3 and 2 mm; and 33% between 2 and 1 mm). These data indicate that the BR sample had a lower particle size than the GL sample.

Figure 1 shows the appearance of the extrudates and the impact of the addition of different concentrations of BR and GL.

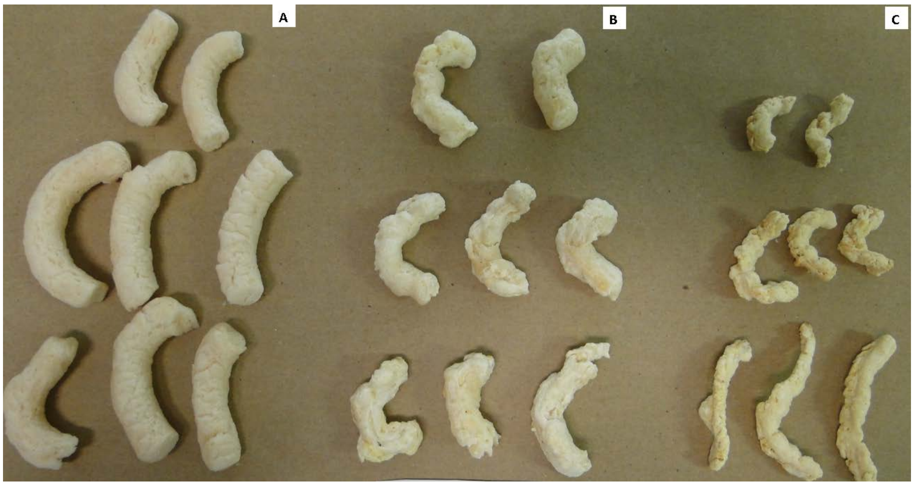

Figure 1. Extruded samples prepared with different concentrations of broken rice and ground lupine. Sample A: 100% broken rice (100BR); Sample B: 90% broken rice and 10% ground lupine (90BR10GL); Sample C: 80% broken rice and 20% ground lupine (80BR20GL).

Table 1. Percent (%) of broken rice and ground lupine retained on each sieve.

Aperture sieve (mesh)	BR	GL
4	0	0
6	0	5
9	0	54
16	97.5	33
35	1.25	5
Collector	1.25	3

BR = broken rice; GL = ground lupine.

The 90BR10GL and 80BR20GL samples showed a lower degree of expansion and more irregular shapes than the 100BR sample. Major changes occurred in the appearance of the 80BR20GL sample because this sample had a high protein content and a low starch content.

The 100BR, 90BR10GL and 80BR20GL samples had EI values of 3.04%, 2.04% and 1.67%, respectively. A reduction in the rate of expansion was observed as GL was added to the extrudate samples. The average rate of expansion of the first two samples (100BR and 90BR10GL) was 2.54%, and there was no significant difference between the results. However, there was a significant reduction in this ratio to 1.67% when the protein content increased as observed in the 80BR20GL sample.

Regarding the ratios of absorption and solubility in water (WAI and WSI, respectively) of the three extruded samples studied, the 100BR sample showed significantly higher values for both WAI (8.96) and WSI (54.46) compared to the other samples. The ratios obtained for the 90BR10GL sample were also higher (7.09 and 16.83 for WAI and WSI, respectively) than those for extruded 80BR20GL (6.30 and 10.47 for WAI and WSI, respectively). Samples with higher starch content showed higher values of WAI and WSI, and these values decreased as the concentration of GL increased. The texture of the extruded products is of great importance to quality and directly affects acceptability to consumers (Borba, *et al.*, 2005). The data in **Table 2** show the texture values for the extruded samples with different concentrations of BR and GL. It was observed that an increase in the number of spikes promoted the crispness and brittleness of the product. Moreover, less shear force resulted in lower hardness of the extrudate. In terms of the number of peaks, the 90BR10GL sample showed the highest number of peaks (10.2) among the three extrudates analyzed. Extruded 80BR20GL had an intermediate number of peaks (7.4), which was less than that of the 90BR10GL sample (10.2) and higher than that of the 100BR sample (3.3).

Use of high shear force was required to cause rupture of the extruded 80BR20GL sample (62.0). For the 100BR and 90BR10GL samples, the force used was 48.4 and 37.9, respectively, and no significant differences were observed in the required shear force.

Another important parameter in assessing the quality of the extruded product is the color coordinates of the samples before and after the extrusion process. **Table 3** shows the values of the CIE color scale parameters for the 100BR, 90BR10GL and 80BR20GL extrudates. After the extrusion process, the brightness of the 100BR sample was significantly reduced from 91.14 to 81.14 compared to the sample of raw rice grits. It is noteworthy that the brightness values of the 100BR sample were lower than those of all other samples studied (BR, GL, 90BR10GL and 80BR20GL). We also observed a significant increase in L^* with increased lupine concentration in the extruded samples ranging from 81.14 (100BR) to 85.08 in the 90BR10GL sample and to 86.24 in the 80BR20GL sample.

Table 2. Hardness and brittleness of extruded samples.

Sample	Peak number	Force (N)
100BR	$3.3^c \pm 1.3$	$44.01^b \pm 4.29$
90BR10GL	$10.2^a \pm 1.6$	$38.87^b \pm 4.28$
80BR20GL	$7.4^b \pm 1.9$	$83.26^a \pm 21.77$

Mean values ± standard deviation (n = 3). Numbers with the same superscript letter in the same row do not differ significantly ($p \leq 0.05$; Tukey's test). 100% broken rice = 100BR; 90% broken rice and 10% ground lupine = 90BR10GL; 80% broken rice and 20% ground lupine = 80BR20GL.

Table 3. CIE color parameters (L^*, a^*, b^*, c^* and h^*) of raw materials and extrudate samples.

Sample	L^*	a^*	b^*	c^*	h^*
BR	$91.14^a \pm 0.03$	$0.11^e \pm 0.0$	$8.14^e \pm 0.02$	$8.14^e \pm 0.02$	$89.22^a \pm 0.00$
GL	$84.31^d \pm 0.06$	$4.03^b \pm 0.04$	$32.08^a \pm 0.15$	$32.33^a \pm 0.15$	$82.82^d \pm 0.07$
100BR	$81.14^e \pm 0.05$	$5.02^a \pm 0.02$	$20.73^c \pm 0.05$	$21.32^c \pm 0.04$	$76.36^e \pm 0.09$
90BR10GL	$85.08^c \pm 0.02$	$2.19^c \pm 0.01$	$20.02^d \pm 0.05$	$20.14^d \pm 0.05$	$83.75^c \pm 0.04$
80BR20GL	$86.24^b \pm 0.08$	$1.65^d \pm 0.03$	$22.21^b \pm 0.08$	$22.27^b \pm 0.08$	$85.73^b \pm 0.10$

The L^* parameter indicates lightness. The a^* and b^* parameters are the chromaticity coordinates that indicate red ($+a^*$), green ($-a^*$), yellow ($+b^*$) and blue ($-b^*$). The c^* parameter indicates the intensity of the color, and h^* indicates hue. Mean values ± standard deviation (n = 3). Numbers with the same superscript letter in the same column do not differ significantly ($p \leq 0.05$; Tukey's test). Uncooked broken rice = BR, ground lupine = GL, 100% broken rice = 100BR; 90% broken rice and 10% ground lupine = 90BR10GL; 80% broken rice and 20% ground lupine = 80BR20GL.

For the a^* parameter, there was an inverse relationship. The a^* values decreased as the concentration of GL increased in extruded samples from 5.02 in the 100BR sample (redder) to 2.19 and 1.65 for the 90BR10GL and 80BR20GL samples, respectively. Furthermore, parameter a^* increased after the rice samples were subjected to the extrusion process. The BR showed lower values of a^* compared to the extruded 100BR sample.

It was not possible to establish a relationship between the b^* parameter and the addition of lupine in mixtures of rice and GL. The GL sample showed higher b^* values (32.08) than the other samples, while the BR sample had a lower b^* value (8.14), thereby indicating that the GL sample had a more yellowish tinge. The b^* values determined for 80BR20GL were higher (22.21) than those of the other extruded samples indicating a higher degree of yellow, which was expected given that this sample had the highest concentration of raw lupine. The 100BR sample showed intermediate (20.73) and significantly higher b^* values than the 90BR10GL sample (20.02). The c^* values were higher for the GL sample and lower for the BR sample, indicating that the GL sample had a higher color intensity than the other samples and that the BR sample had a lower intensity.

The h^* values indicate the tones of the samples as follows: values close to 0, 90, 180 and 270 indicate a red, yellow, green and blue hue, respectively. Thus, the values found for all samples suggested that the yellow tint increased as the concentration of lupine in the extruded samples increased.

The overall appearance of the raw materials and extrudates could be assessed by the micrographs obtained by scanning electron microscopy.

The images shown in **Figure 2** are images of the raw materials, including BR and GL, before being subjected to the extrusion process.

Figure 2 shows small starch granules on the surface of the rice samples (A2 and A3), and these samples were also stratified with spaces between the particles.

Figure 3 shows the images of the samples after the extrusion process obtained by scanning electron microscopy.

The samples shown in **Figure 3** were more compact, and it was not possible to observe individual starch granules.

4. Discussion

White rice has high total starch content (87%), and it is composed of 0.3% fat, 2.8% total dietary fiber (1.0 and 1.8% insoluble and soluble fiber, respectively) and 8.9% protein. White rice is characterized by low levels of ly-

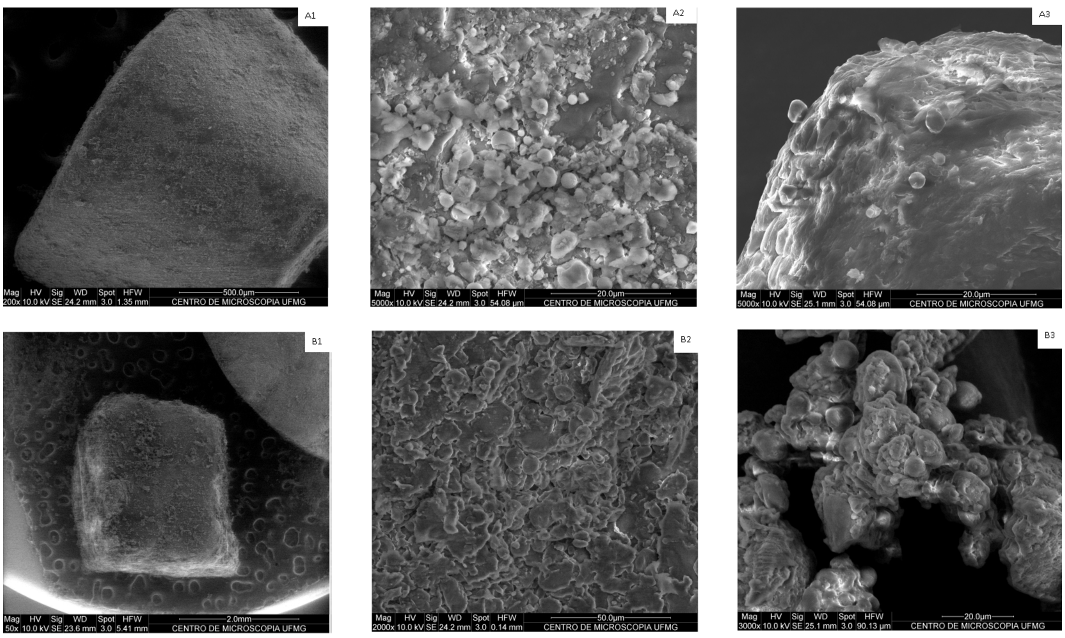

Figure 2. Scanning electron microscopy of broken rice, lupine and their respective flours. A = rice matrix; A1 = broken rice, 200×; A2 = surface broken rice, 5000×; A3 = rice flour, 5000×; B = lupine matrix; B1 = broken lupine, 50×; B2 = broken surface lupine, 2000×; B3 = broken lupine, 3000×.

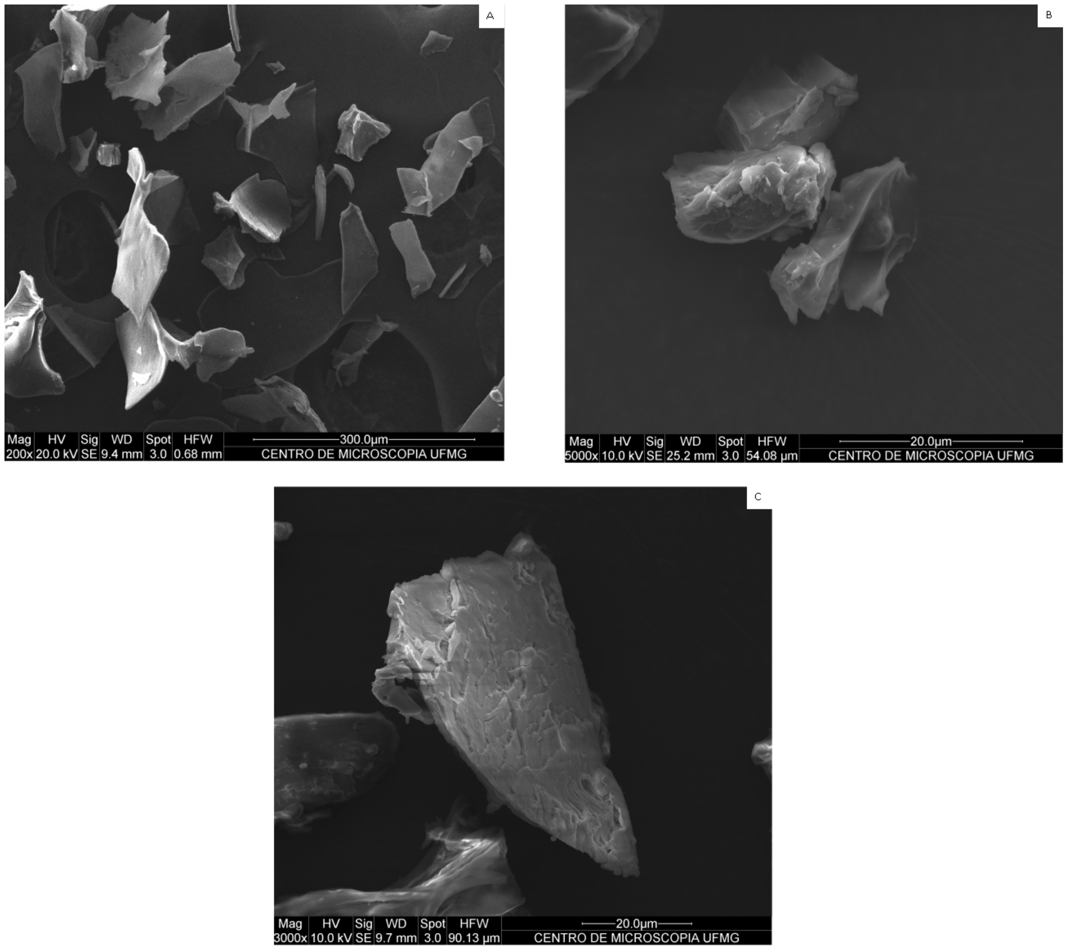

Figure 3. Scanning electron microscopy of extruded samples. A = 100BR, 200×; B = 90BR10GL, 500×; C = 80BR20GL, 5000×.

sine and threonine and by high concentrations of sulfur-containing amino acids, such as methionine and cysteine. Cereals have a low content of thiamine and riboflavin vitamins but high concentrations of niacin [15].

Thus, using different proportions of lupine and rice grains, food with better nutritional composition, *i.e.*, with high biological value, can be developed if the amino acid composition of each component complements each other. Furthermore, rice grains with a composition rich in starch are favored for use in various foods, such as pasta, that are extruded and for use in bread-type baked products.

Adding 10% white lupine grains to samples of BR resulted in a 10% reduction in total starch and a 27% increase in protein, in addition to elevating the levels of arginine, glycine, isoleucine, leucine, lysine and aspartic acid by 45%, 29%, 39%, 25%, 39% and 47%, respectively, in the final mixture.

Based on the recommended daily intake of essential amino acids, a 60 kg adult should eat 840, 1149, 2520, 2280, 1140, 1980, 1200, 300 and 240 mg of histidine, isoleucine, leucine, lysine, methionine/cysteine, phenylalanine/tyrosine, threonine, tryptophan and valine, respectively [16].

Thus, by consuming a 100 g portion of a mixture of 80% BR and 20% GL, there is a 21%, 50%, 46%, 30%, 26%, 42%, 44%, 43% and 283% increased intake of the daily requirement of histidine, isoleucine, leucine, lysine, methionine/ cysteine, phenylalanine/tyrosine, threonine, tryptophan and valine, respectively, thereby indicating a significant increase in the content of essential amino acids by mixing lupine and rice.

The composition of the raw material, its moisture content and the size of its particles influence the viscosity of the product in the extruder. Small particles, such as flour, are more easily hydrated and cook more quickly than larger particles, thus changing the final product quality [17], which partially explains why the BR had the smallest particle size because it was the sample that had the highest starch content.

Increased concentrations of lupine in the extruded products resulted in less expansion. This fact can be explained by the increase in the protein content and the reduction in the starch content caused by adding lupine to samples of BR used to produce the extrudates.

Soares Jr. *et al.* (2011) evaluated the EI in extrudates using different concentrations of rice and bean flour (rice flour:bean flour ratios of 0:100, 25:75, 50:50, 75:25 and 100:0), and they observed that this index increased as the concentration of rice flour increased and the concentration of bean flour decreased, which was similar to the observations in the present study with mixed rice and lupine. [18] In both studies, the expansion ratios were higher in the extruded samples with higher concentrations of rice or higher starch content.

Maia *et al.* (1999) observed a reduction in WAI with increasing soy flour content in extrudates prepared with rice flour and soy, which was attributed to the higher protein content, thereby confirming the results in the present study [19].

One factor that determines the acceptability of extrudate to the consumer is the texture, which should have low hardness [17] [20]. The 90BR10GL sample showed the greatest strength and least brittleness, resulting in lower hardness and greater crispness.

Chen *et al.* (1991) reported that the crispness, hardness and extrudate chewing are associated with the expansion rate of the extrudate. In general, the expansion of the product is directly related to the texture, and products with greater expansion are crispier [21].

Evaluating both the expansion and hardness of the extruded products, it was noted that among the samples with higher EI (100BR and 90BR10GL), 90BR10GL presented the highest crispness.

According to Teba (2009), the color formation during the extrusion process depends on the temperature of the heat treatment and is directly related to the composition of the formulation [1].

The changes in colors observed in extruded products may be due to caramelization or the Maillard reaction, especially in materials that have relatively high levels of reducing sugars, which are favored by processing conditions browning occurring in the extruded products [17].

The enhanced brightness in the extrudate can be explained by a decrease in the starch content in the extruded samples due to the addition of GL. Therefore, these grains are minimally affected by caramelization and Maillard reactions. Increasing the concentration of lupine and decreasing the rice in the extruded samples reduces the starch content and reducing sugars in the extrudate. Consequently, caramelization and Maillard reactions are minimized resulting in elevated luminosity in extrudates containing lupine.

Furthermore, redder and yellower shades in samples containing lupine were observed. This difference in color was expected because the grains of white lupine have a yellowish tint whereas rice has a whiter color.

The compact and amorphous appearance of the extrudate without starch granules found in the present study may be explained by the fact that during extrusion, the starch (initially in granular form in the presence of humidity) is progressively compressed and transformed into a dense, solid, compact material in which the crystal grain structure disappears [22].

5. Conclusions

The product of the mixture prepared from extruding BR and GL had an improved amino acid profile.

There were decreases in the EI, WAI and WSI values as the concentration of lupine increased. The extruded sample with milled lupine showed a large conformational change relative to the 100BR sample, thus preventing its use as a snack. However, preparations with different concentrations of GL extrudates may be used in the form of pre-gelatinized flour in the preparation of various instant foods, such as soups and noodles.

The extruded flours showed increased brightness as the concentration of lupine increased in the extruded mixtures due to a reduction in the starch content, and consequently, the minimization of browning reactions, such as caramelization and Maillard reactions. However, samples produced with lower amounts of lupine, and consequently, higher starch contents showed a more reddish color.

By scanning electron microscopy, we observed a reduction in the presence of starch granules after the extrusion process, with the product having a more amorphous and compact structure after starch gelatinization.

We intend to develop and enrich food products with extruded rice flour and lupine.

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