Optimization of extrusion variables for the production of snacks from by-products of rice and soybean

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Abstract

This study aimed to define the process conditions to obtain snacks from the by-products of rice and soybean with physical characteristics suitable for marketing. Therefore, the effects of moisture and extrusion temperature on the expansion and color of the products obtained experimentally obtained were evaluated, and the proximate composition of the by-products and that of the snack with greater desirability were determined. Response surface methodology and rotational central composite design were used, and desirability test based on the regression models adjusted was applied. The most desirable snack, with the highest expansion index (3.39), specific volume (13.5 mL.g^{-1}), and the chromaticity coordinate a* (2.79), was obtained under 12 g.100 g^{-1} moisture and 85°C of temperature in the third zone of the extruder. The snack produced under these conditions attained content of protein and lipid content 41 and 64% higher than that of the traditional corn snack. It can be concluded that producing extruded snack made form a mixture of broken grains, rice bran, and soybean okara (81:9:10) is technologically feasible, enabling the development of a new product with good nutritional value that can improve the diet of children, the main consumers of this type of food.

Keywords: *Oriza sativa* L.; *Glycine max* L.; processing; expansion; color; sustainability.

1 Introduction

Corn grits are the main raw material for commercial production of extruded snacks. They have high porosity, crunchy texture, and are palatable Ascheri et al. (2003). Recently, some other raw materials, mainly agribusiness by-products derived from the processing of grains, roots, and tubers have been studied in order to replace corn grits in the manufacture of snacks. Some starch-rich by-products are economically viable, and therefore are more convenient for obtaining expanded products (SOARES JUNIOR et al., 2011; CARVALHO et al., 2012). Brazil has an outstanding production of rice (*Oryza sativa* L.) and soybean (*Glycinemax* L.) generating large amounts of by-products in the processing of these commodities.

Rice is the second largest produced cereal worldwide, behind wheat only. It is estimated that in the 2012 crop, 730 million tons of paddy rice were produced. Brazil has a good share in world production of this grain and is considered the tenth global consumer (FOOD…, 2013). The estimated world production of soybean in the 2012 was 271.3 million tons, and Brazil produced 78 million tons, the second largest producer (HECK, 2012).

During rice processing, broken grains rich in carbohydrates (89.9 g.100 g^{-1}), mainly starch and bran, are generated. These grains have variable amounts of starch, but they are nutritionally beneficial because they are a source of protein (13.4 g.100 g^{-1}) (PESTANA, MENDONÇA, ZAMBIAZI, 2008).

In addition to the intensive use of soybean for the production of oil and meal, there has been an increased use of water soluble soybean extract or soy milk. The soybean market has been growing markedly in recent years (93%), especially in the beverage segment, and the ready-to-drink juice market has grown 25% in the same period due to consumer demand for healthy and practical products (JAEKEL; RODRIGUES; SILVA, 2010). Thus, there has been a large production of rice and soybean by-products derived from the manufacturing process of these grains.

Okara is the residue obtained, specifically in the filter, in the production of water soluble soybean extract (SILVA; CARRÃO-PANIZZI; PRUDÊNCIO, 2009). With regard to chemical composition, okara has high protein, averaging 42.5% on a dry basis. Approximately one third of soybean isoflavones remain in okara. Thus, this by-product, in addition to having the potential to be used as a source of nutrients, it is also a source of isoflavones (LI et al., 2012). Studies indicate that the consumption of soybean by-products and their derivatives provides health benefits, such as prevention and therapeutic treatment of cardiovascular diseases reduced risk of cancer and osteoporosis, and alleviation of menopausal symptoms (MOLINA; FEIHRMANN, 2009).

The production of extruded snacks from the by-products of rice and soybean can be a great alternative to producing processed food of commercial interest due to the expansion characteristics of the mixture (rich in starch) and the nutritional value from the higher protein content and better profile of essential amino acids of soybean and rice relative to corn

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(LI et al., 2012; LIMBERGER et al., 2009). In the present study, the best extrusion condition was determined considering the aspects of expansion and color as a function of the mixture moisture and temperature in the third zone of the extruder, in addition to the physical and chemical quality parameters of the snacks produced using the best technological condition.

2 Materials and methods

The broken grains and rice bran (blend of the cultivars IRGA 417 and IRGA 424-2012 harvest), were donated by the company Cristal Alimentos Ltda., located in Aparecida de Goiânia (Goiás, Brazil); black soybean was acquired in Cerealista São José, located in São Paulo (São Paulo, Brazil). The rice by-products, broken grains and rice bran, were used on the day following their production in the form they were acquired. In order to obtain the dried black soybean okara, the grains were soaked in boiling water for 5 minutes to inactivate the antinutritional factors of the legume, according to Bellaver and Snizek Junior (2009).The okara produced was dried in an air circulation oven (*Technal TE-394, Piracicaba, Brazil*) at 60 °C for 10 hours.

The particle size of the by-products of rice and soybean was determined using a vibrating equipment (*Produtest, Mod. T, São Paulo, Brazil*), according to the method described by Dias and Leonel (2006). Micrographs of the by-products were obtained using a scanning electron microscope (*Sputter Coater*, SCD-050, *Scotia*, *USA*), with 3000x and 6000 x magnification, after drying the samples in an air circulation oven at 60°C for 24 hours; The samples remained in a desiccator until analysis. They were then mounted with double-sided tape on aluminum stubs and were coated with gold (15 nm thick).

After the preliminary tests, the snacks were prepared from a mixture of broken rice grains, rice bran, and dried black soybean okara (81: 9: 10), homogenized for 15 minutes using a Y-type mixer. The mixture was packed using different moisture levels according to the values set in the experimental design. The coded values of the independent variables were-1.41; -1; 0; 1; and 1.41, while the actual temperature values of the third zone of the extruder ranged between 60 and 110°C and moisture between 12 and 20 g.100g^{-1}. The samples with different moisture contents were kept under refrigeration for 24 hours before use. The amount of water to be added to the samples was calculated based on the amount of mixture to be extruded and on its initial moisture content (Equation 1).

$$Q_w = \{[\frac{(M_f - M_i)}{(100 - M_f)}] * 100\} * M_s \tag{1}$$

where: Q_w = quantity of water to be added into the mixture (g); M_f = final moisture content (g.100 g^{-1}); M_i = initial moisture content of the sample (g.100 g^{-1}); and M_s = mass of the sample (g).

The thermoplastic extrusion was performed using a single screw extruder machine (*Inbramaq, PQ-30, Ribeirão Preto, Brazil*). The processing parameters used were: screw speed of 250 rpm (60 Hz), circular die opening of 4 mm diameter, pre-die with 22 holes, screw with three inputs and 30 cm length, screw compression ratio of 3:1, helical barrel design, feed rate (335 g.min^{-1}); and barrel temperature in the first and second heating zone of 40° C and 60° C, respectively.

The volume of the snacks was determined according to the mass displacement method (millet seed) in 10 replications; the mass was measured using a semi-analytical scale. The specific volume (SV) was calculated by the ratio between the average volume and the mass of snacks, according to the method described by Leonel, Souza and Mischan (2010). The expansion index (EI) was determined by the ratio between the diameter of the extrudate and the diameter of the output hole of the extruder (4 mm), according to the method described by Faubion and Hoseney (1982). A caliper (*Digital Caliper, Messen, Danyang, China*) was used to measure the diameter of the extrudate, and the arithmetic mean was calculated from 10 randomly chosen snacks per experiment. The snacks were evaluated for instrumental parameters of color, following the method proposed by Paucar-Menacho et al. (2008), according to the CIEL L*, a* and b* system with a colorimeter (*Color Quest, XE, Reston, EUA*) using the standard illuminant D65 (corresponding to natural daylight), and an observation angle of 10°.

The proximate composition and energy value of the rice and soybean by-products and the selected snack were determined. Moisture was determined as the mass loss measured by drying the sample in an oven at 105 °C until constant weight. Protein concentration was determined by the Kjeldahl method for the determining total nitrogen content, which was converted into crude protein by the conversion factor of 6.25 for soybean and 5.95 for rice by-products. Lipid content was determined by the Bligh-Dyer method for cold extraction with chloroform, methanol and water at the ratio of 1:2:0.8 (v/v); ash content was determined by carbonization, followed by complete incineration in a muffle furnace at 550°C, and carbohydrates were calculated by difference by as 100 − (moisture + ash + protein + fat) (ASSOCIATION…, 2005). The crude fiber was determined by the Scharrer-Kürschner method, as described by Angelucci et al. (1987), using nitric acid, trichloroacetic acid, and acetic acid for hydrolysis. The total energy was estimated using the Atwater conversion factors; the content of carbohydrate (minus the crude fiber content) and protein were multiplied by four; lipid content was multiplied by nine, and the sum of the products' content resulted in the value of total energy (BRASIL, 2003). The chemical composition data of the snacks evaluated were compared with those of the corn snacks reported by Bombo (2006).

The Central Composite Rotational design was used with 11 experiments and three replicates at the central point (RODRIGUES; IEMMA, 2005). Data from EI, SV, L*, and chrome a* and b* of the snacks were evaluated by analysis of variance with the construction of multiple regression models and level curves to identify the effect of the independent variables on the responses using the Statistica software (*Statsoft, Statistica 7.0, Tulsa, USA*). Based on the significant mathematical models (P <0.10) and using the function Response Desirability Profiling of the software Statistica, the most desirable snack depending on the moisture and extrusion temperature used was determined. The most desirable snack was considered the one with higher values of EI, SV, and chromaticity a*. The optimization technique was based on the definition of a function of restricted desirability in the range 0-1, for which the lower, middle, and upper limit values were defined as 0, 0.5, and 1.0, respectively, for the dependent variables studied (STASOFT, 2007). After determining the best process conditions to obtain the most desirable snack, a new extrusion was carried out under these conditions to validate the mathematical models.

3 Results and discussion

The low levels of moisture found in the by-products are desirable (Table 1) since moisture values below 14 g.100g^{-1} can prevent microbial growth, improve chemical and enzymatic stability, and increase the shelf life of products (BARBOSA-CÁNOVAS et al., 2007). The ash content of rice bran was 45 times higher than that of the broken grains and 9 times higher than that of the okara soybean, which may be an advantage in terms of mineral contents, while the mean value of lipids in the broken rice grains was low, 4% less than that found in okara and 5% less than that of rice bran.

The soybean okara showed values 7.2 and 41.2 times higher in protein and crude fiber, respectively, than those of the broken rice grains, which had 43 and 172% more total carbohydrates than rice bran and soybean okara, respectively. Soybean okara showed the highest total energy, 14% higher than that of the rice bran and 32% higher than that of the broken rice grains. Based on the determination of crude fiber rather than the determination of dietary fiber, the fiber content was underestimated. On the other hand, the energy value was overestimated. The results obtained indicate that the rice bran and soybean okara were rich in lipid, protein, and fiber, which increase the energy value.

The particle size data of rice and soybeans are shown in Table 2. The uniformity index (UI) of the broken rice grains was 6:4:0 (60% coarse particles and 40% medium particles); for soybean okara it was 7:3:0 and for rice bran it was 0:6:4. Therefore, soybean okara was the by-product with highest uniformity.

It can be considered that the soybean okara and broken rice grains had a coarser particle size (100% of the particles were medium sized and coarse), similar or even larger than those of the corn grits (ASCHERIR et al., 2002). In contrast, rice bran showed finer grain size (100% between medium and fine), which were obtained due to bran removal and grain polishing during processing. Working with large particles of broken grains and okara without prior grinding facilitated feeding the extruder avoiding the formation of air chambers within the volumetric feeder. Despite the differences in particle size of the mixture's components, there was no negative effect on the extrusion process. The homogeneity of the particles promotes the proper and uniform cooking of the raw material during the extrusion process by preventing hardness and partial cooking, which causes undesirable particles with different degrees of cooking compromising the quality of the extruded product, both in terms of appearance and palatability (BORGES et al., 2003). In the present study, the presence of unwanted particles in the snacks was observed only under milder process conditions, low temperature and low moisture.

The rice broken grains and rice bran showed large amounts of uniform microscopic appearance with rounded starch granules with an average diameter of 5.4 m, which were either loose or clustered in a protein matrix, but intact (Figure 1A and 1C). In the rice bran it was also observed the presence of fibers derived from the pericarp of the caryopsis, while the okara had uneven elongated shape structures typical of soybean protein and fiber (Figure 1B).

The influence of moisture and temperature on the final appearance of the snacks obtained in the different treatments was evident (Figure 2). The snacks extruded at lower levels of

Table 1. Proximate composition and energy value of the rice and soybean by-products[1].

Component	Broken rice grains	Rice bran	Black soybean okara
Moisture[2]	10.45± 0.19 (1.86)	3.54 ± 0.17 (4.99)	2.26 ± 0.04 (1.61)
Ashes[2]	0.22 ± 0.02 (11.7)	10.20 ± 0.19 (1.83)	2.27 ± 0.14 (6.18)
Lipids[2]	0.96 ± 0.06 (5.94)	18.32 ± 0.07 (0.36)	24.73 ± 0.11(0.43)
Protein[2]	6.52 ± 0.16 (2.41)	10.89 ± 0.14 (1.25)	40.66 ± 0.07 (0.16)
Crude fiber [2]	0.17 ± 0.02 (11.76)	5.61 ± 0.13 (2.31)	7.07 ± 0.20 (2.83)
Total carbohydrates[2]	81.85	57.05	30.08
Energy value[3]	361.39	418.90	477.17

[1]Mean value ± standard deviation (coefficient of variation); [2]g.100 g^{-1}; [3]kcal.100g^{-1}.

Table 2. Percentage of samples retained on the sieves during the analysis of the particle size of the by-products of rice and black soybean used in the formulation of snacks.

Tyler	Hole (mm)	Rice bran (%)	Broken rice grains (%)	Soybean okara (%)
32	2.00	3.31	62.76	68.74
60	0.25	63.07	36.92	31.02
100	0.15	32.06	0.32	0.24
150	0.106	1.28	0	0
270	0.053	0.28	0	0
Sieve bottom	0	0	0	0

moisture and temperature in the third zone of the extruder were grayish, lighter than those in the treatments with higher moisture and lower temperatures, which were expanded and darker snacks.

The experimental design and the results are shown in Table 3. The significance levels of the effect of temperature and moisture (linear, quadratic, and interaction), the model adjusted, and coefficient of determination (R^2) of the properties expansion and color are shown in Table 4.

The models for brightness (L*) and chromaticity coordinate b* were not significant ($P > 0.10$). The other models were significant ($P \leq 0.10$), with coefficients of determination explaining between 67 and 80% of the responses. The EI of the snacks ranged from 2.33 to 3.61, with a difference of 55% between the treatments. The quadratic effects of temperature and moisture and the linear effect of moisture were significant in the model ($P < 0.10$) (Table 4). The graph area with higher EI values (above 3.0) has a semi-elliptical shape and is situated between moisture values of 13.2 to 16.2 $g.100g^{-1}$ and temperatures above 83°C (Figure 3A).

Silva and Ascheri (2009) extruding broken rice found values of EI between 3.5 and 11.2. The highest values were observed with humidity between 15-16% and temperatures between 140-160 °C. In the present study, the maximum temperature used was 110 °C and the use of rice bran and soybean okara (rich in fiber and lipids) (Table 1) may explain the lower IS values obtained. Aschieri and Carvalho (2006) studied extrusion of rice flour with 10, 15, and 20% of soybean peels (crude fiber ranging from 14.54 to 20.1) and obtained EI values between 4.37 and 4.90. The presence of fiber can break the walls of the bubbles in the product preventing its maximum expansion (LUE; HSIEH; HUFF, 1991). According to Soares Junior et al. (2011), snacks with different proportions of rice flour and bean flour (3.2-5.3% lipids) resulted in EI values between 2.0 and 3.9. The treatment with less bean flour showed the highest EI. Kumagai, Lee and Yano (1987) observed that the volume of extruded made with defatted rice flour was 50% larger than that of the extruded

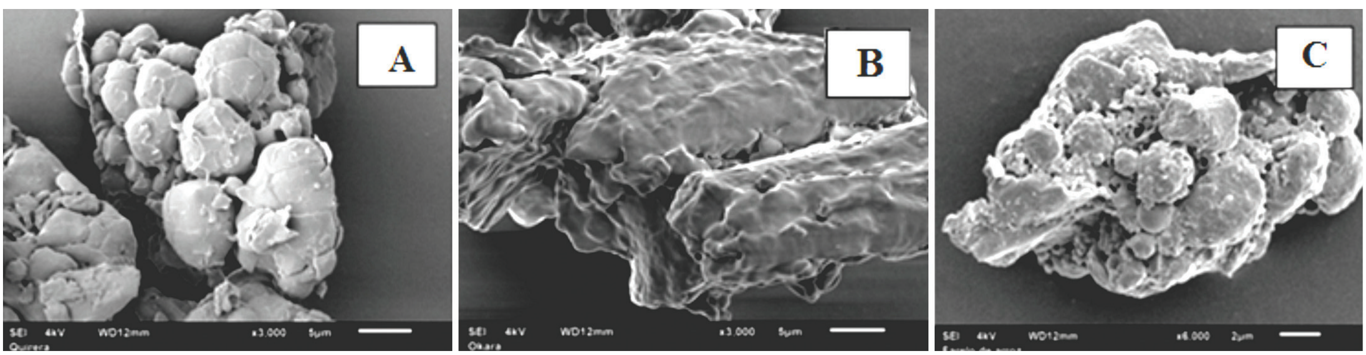

Figure 1. Scanning electron microscopy: (A) broken rice grains at 3000x magnification, (B) dried black soybean okara at 3000x; (C) rice bran at 6000x.

Figure 2. General appearance of experimental snacks produced from by-products of rice and soybean (experiment 1-8). Experiment 1 (moisture 13.16 $g.100^{-1}$; temperature 67.3 °C); experiment 2 (moisture 13.16 $g.100^{-1}$; temperature 102.7 °C); experiment 3 (moisture 18.84 $g.100^{-1}$; temperature 67.3 °C); experiment 4 (moisture 18.84 $g.100^{-1}$; temperature 102.7 °C); experiment 5 (moisture 16 $g.100^{-1}$; temperature 60 °C); experiment 6 (moisture 16 $g.100^{-1}$; temperature 110 °C); experiment 7 (moisture 12 $g.100^{-1}$; temperature 85 °C); experiment 8 (moisture 20 $g.100^{-1}$; temperature 85 °C).

rice flour. In the present study, the radial expansion was less pronounced, probably due to the lipid content of the rice bran and soybean okara.

As for the SV, there was a variation of 133%, from 5.9 to 13.8 mL.g^{-1}. The linear trend of moisture was negative and significant, while that of interaction was positive and significant ($P<0.10$). (Table 4). The highest values of SV (above 12.0 mL.g^{-1}) were found in the area comprising temperatures below 92°C and moisture below 13.6 g.100 g^{-1}, and the lowest SV values (below 7,5 mL.g^{-1}) were found at temperatures above 102°C and moisture above 16.6 g.100 g^{-1} (Figure 3B). According to Ding et al. (2005), water has the opposite effect on expansion, acting as a plasticizer for starch materials, reducing its viscosity and dissipating the mechanical energy in the extruder, and thus the product becomes denser and the bubble growth is compressed, as observed in the present study. Camargo, Leonel and Mischan (2008) studied the effect of moisture and extrusion temperature on the specific volume of snacks of cassava starch and soy flour, and reported values between 1.5 to 5.6 mL.g^{-1}, which are lower than those found in the present study.

Corn snacks usually have specific volume with values similar to those found in the present study. Alves and Grosmann (2002) reported that the SV of commercial corn snacks can reach up to 8.4 mL.g^{-1}, value within the range of SV observed for the snack produced from rice and soybean by-products.

The color of the snacks is a very important feature for the marketing, and it is influenced by the raw materials that make up

Table 3. Experimental design and results of expansion index (EI), specific volume (SV), brightness (L*), chromes a* and b*, and color difference (DE) compared to the color of raw mixture (A) of the extruded snacks according to temperature (x_1) and moisture (x_2).

Exp.	Encoded value		Real value		Physical property		
	Temp. (x_1)	Moisture (x_2)	Temp. (°C)	Moisture (g.100g^{-1})	SV	EI	a*
1	–1	–1	67,3	13,16	13,5	2,62	2,59
2	1	–1	102,7	13,16	11,71	2,59	2,72
3	–1	1	67,3	18,84	6,97	2,33	1,96
4	1	1	102,7	18,84	13,81	2,55	2,52
5	–1,41	0	60	16	7,75	2,64	2,05
6	1,41	0	110	16	8,4	2,92	2,79
7	0	–1,41	85	12	13,5	3,39	2,52
8	0	1,41	85	20	5,92	2,28	1,79
9	0	0	85	16	11,07	3,23	2,28
10	0	0	85	16	11,26	3,61	2,44
11	0	0	85	16	11,87	3,42	2,38

Table 4. Adjusted models of expansion index (EI), specific volume (SV), and chroma a*, correlation coefficient (R^2), and effects of temperature (x_1) and moisture (x_2).

Physical parameter	Level of significance (ANOVA)					Adjusted model	R^2
	T (L)	T (Q)	U (L)	U (Q)	TxU		
EI	-	0.01	0.04	0.01		$y= 3.42-0.39x_1^{2}-0.24x_2-0.37x_2^{22}$	0.78
SV	-	0.25	0.03		0.06	$y=11.22-0{,}95x_1^{2}-1.90x_2+2.16x_1x_2$	0.67
a*	0.005	-	0.003	-	-	$y= 2.37+0.22x_1-0.24x_2$	0.80

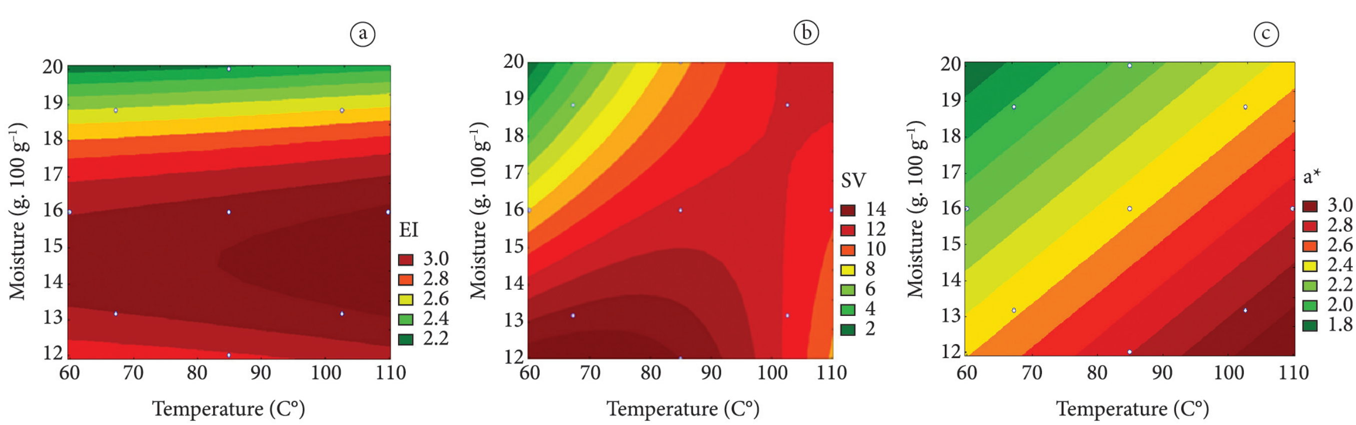

Figure 3. (A) Expansion Index (EI), (B) specific volume (SV) (mL g^{-1}); and (C) chroma a* of snacks produced from by-products of rice and black soybean according to the mixture's moisture and extrusion temperature in the third zone of the extruder.

their formulation (CARVALHO et al. (2012). Brightness (L*) of snacks varied between 72.6 and 78, and chromaticity coordinates a* and b* from 1.79 to 2.79 and from 9.45 to 11.85, respectively. The effects of moisture and temperature were not significant for L* and b*; therefore, these parameters were not used in the desirability test because the regressions were not significant ($P > 0.10$). Borba, Sarmento and Leonel (2005) reported increased intensity of yellow (increased chrome b*) when the product was extruded, and they justified this observation as a result of the low moisture content during processing, favoring the occurrence of non-enzymatic browning reactions. In the present study, the intensity of yellow generally increased with lower moisture values (around 12 g.100 g^{-1}), suggesting an effect of the moisture verified by these authors. The b* values were also low, differing from those of traditional corn based-snacks, which have high content of carotenoids that provide greater yellowish tint that can be improved with the use of natural dyes such as annatto powder, as reported by Leonel, Souza and Mischan (2010).

With regard to chrome a*, although its variation was small, the positive linear effect of extrusion temperature and the negative effect of the mixture moisture were significant ($P < 0.10$). Higher values of chrome a* (above 2.6) were observed at temperatures above 76.7°C and moisture below 16.9 g.100g^{-1} (Figure 3C). According to Lacerda et al. (2010), the Maillard reactions and caramelization are possible explanations because high temperatures and low humidity in the product processing can make it redder. In accordance with Capriles and Arêas (2012), chrome a* of snacks of corn and amaranth reached 7.4. On average, the chromaticity a* of snacks obtained in the present study was three times lower than that of snacks of amaranth and corn. In general, the snacks appeared to be slightly darker (lower L* values) than the snacks from the rice by-products due to the dark pigmentation of the black soybean okara, despite its lower concentration. The desirable physical properties for the snack were maximum values of EI, SV, and chrome a*, i.e., as close as possible to those of the snack made from corn grits, the most popular product in the market (Figure 2, experiment 7). The snack from rice and soybean by-products with the highest desirability was obtained with a mixture moisture content of 12 g.100g^{-1} and extrusion temperature 85°C (Figure 4), in which it values of 3.39 were estimated for EI, 13.5 mL.g^{-1} for SV, and 2.52 for chromaticity coordinate a*. In the validating the model, the values were very close to these estimated values: SV of 13.25 ± 0.47 mL.g^{-1}, EI of 3.36 ± 0.16, and chromaticity coordinate a* of 2.51 ± 0.03, confirming the predictive ability of the adjusted models.

The most desirable snack produced from by-products of rice and black soybeans (selected) was analyzed for proximate

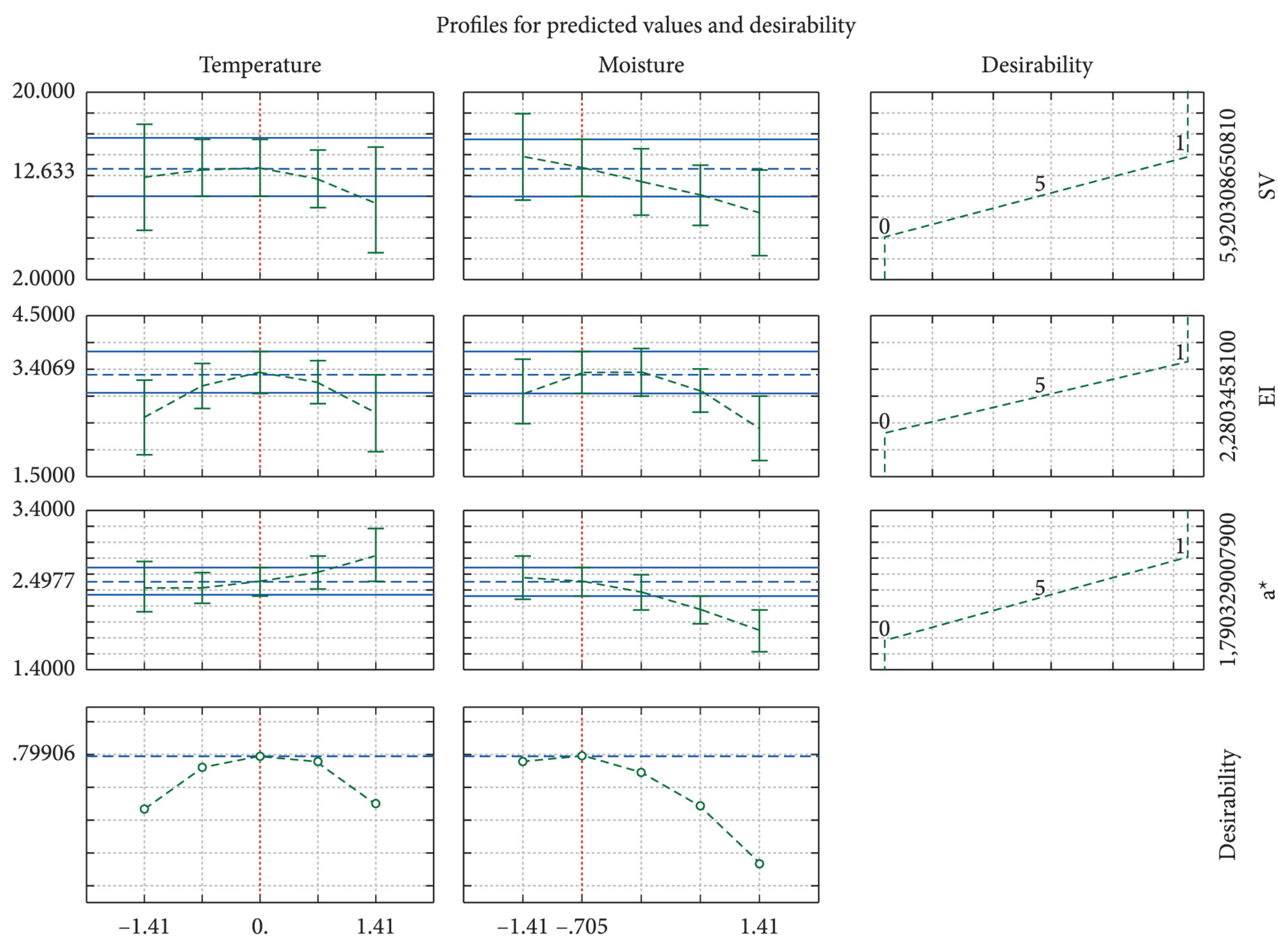

Figure 4. Graphic diagram of desirability aiming to obtain snacks with physical properties required for a product with commercial potential, depending on moisture and extrusion temperature during processing.

Table 5. Proximate composition and energy value of the optimized snack.

Characteristic	Snack produced from by-products of rice and soybean	Snack of corn[2]
Ashes[2]	0.67 ± 0.01	1.79 ± 0.06
Lipids[2]	4.08 ± 0.10	2.49 ± 0.13
Protein[2]	10.50 ± 0.12	7.45 ± 0.80
Crude fiber [2]	1.57 ± 0.09	2.09 ± 0,11
Total carbohydrates [2]	79.35	62.43
Energy value[3]	390.19	332.17

[1]Average followed standard deviation; [2]g. $100g^{-1}$; [3]kcal $(100g)^{-1}$; [2]Bombo (2006).

composition and energy value, which were compared with those of corn snack obtained by Bombo (2006) (Table 5).

Based on the protein content of the snack produced from rice and soybean by-products, it can be said that it is a source of proteins (Table 5). The experimental snack selected had contents of protein, carbohydrates, and lipids of 41, 27, and 64%, respectively; its ash content was 61% smaller than that of traditional corn snack (BOMBO, 2006). With regard to the energy value of corn snacks found by Bombo (2006), the value found in the present study was 17.47% higher due to its lipid content.

4 Conclusion

The extrusion conditions that resulted in snacks with the best physical quality (higher expansion and better color) were: moisture of the mixture of rice and soybean by-products of 12 g.100 g^{-1} and extrusion temperature of 85°C. The combination of large amounts of carbohydrates in the broken rice grains with the proteins and lipids of rice bran and black soybean okara resulted in an extruded product of high nutritional value, with 41% more protein, 64% more lipids, 27% more carbohydrate, and energy value 17% higher than that of the traditional corn snack available in the market. It can be concluded that producing an extruded snack with a mixture of broken grains, rice bran, and soybean okara (81:9:10) is technologically feasible, enabling the development of a new product with good nutritional value that can improve the diet of children, the main consumers of this type of food.

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