EXPANDED GLUTEN-FREE EXTRUDATES MADE FROM RICE GRITS AND BANDINHA (BEAN) FLOUR MIXES: MAIN QUALITY PROPERTIES

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ABSTRACT

The effect of extrusion operating conditions on main quality properties of gluten-free expanded snack-type products, developed from rice grits and bandinha flour formulations, was studied. The protein content in the extrudate varied from 9.44 to 14.74 g/100 g for formulations containing 13 and 47% bandinha flour, respectively, processed at 85C and 15% feed moisture. Apparent density and the radial expansion index of the extrudate were significantly ($P < 0.05$) affected by bean flour content, moisture content, temperature and the interaction between moisture content × temperature. The most suitable extrusion conditions were 30 g/100 g bean flour content, 14 g/100 g moisture content and 80C die temperature, which resulted in a product with a high radial expansion index and crude protein of 9.5 and 13 g/100 g, respectively, and a low apparent density of 0.20 g/cm^3.

PRACTICAL APPLICATIONS

There is a dynamic growth trends taking place in the gluten-free market due to its relationship to celiac disease, wheat allergy, gluten intolerance and gluten sensitivity. To date, most gluten-free products in the market are in the form of pasta and bakery products. However, there is an open niche for gluten-free foods in the form of expanded snack-type products. The flours of underutilized broken rice and beans ("bandinha"), processed under the selected range of extrusion conditions in this study, have great potential for the development of value-added, protein-rich, gluten-free foods in the form of expanded, low-density, snack-type products. The factorial design used to determine the relationship between the independent and the response variables aided to determine the most suitable processing conditions to generate a quality end product.

INTRODUCTION

The United Nations Millennium Development Goals, which were established in 2000, call for hunger to be halved by 2015 (Millennium Development Goals 2000), but it is unlikely that this important aim will be achieved. Additionally, the global economic crisis, the effects of fluctuating weather patterns as a result of climate change, extremely low-grain reserves, high oil prices, the surge in biofuel production and the "meatification" of the global diet have contributed to the high prices for food and to the increase in the number of hunger in recent years (Holt-Gimenez 2008). By 2050, the global population will surpass 9 billion people, and demand for agricultural products is expected to double (World Economic Forum 2010). Broken grains are subproducts generated during the processing of these commodities. These grain subproducts are underutilized, low-cost food ingredients that have great potential for the production of a variety of food products. However, broken grains as cereals and legumes have been mainly used as animal feed.

The kernel of rice can become cracked in the field, during the drying process or during the milling process. Often these cracks cause the kernels to break during milling and so broken rice is generated. The percentage of broken kernels (relative to total milled rice) produced during the milling process usually ranges from 12 to 24%. Broken rice ("grits") tends to get mushy during cooking and makes poor quality table rice. In the case of common beans, broken seeds are also produced during the different steps of bean processing. Broken beans are generally hard to cook and are popularly called "bandinha" in Portuguese.

Rice (*Oryza sativa* L.) and the common bean (*Phaseolus vulgaris* L.) are regarded as staple food in Brazil. Cereal and legume seeds are known to be complementary food ingredients as their combination provides an excellent balance of amino acids in the human diet. Flour from whole rice kernel has been used to produced value-added, extruded rice grains look-like fortified with iron, zinc and vitamin A to improve nutritional status in schoolchildren (Pinkaew *et al.* 2013). However, broken grains of rice (grits) and beans (known as "bandinha") are regarded as raw material of inferior quality to whole seeds and therefore they are underutilized available resources. The common bean is a rich source of nutrients with significant amounts of protein, calories, carbohydrates, unsaturated fatty acids and dietary fibers in addition to important vitamins and minerals for proper human nutrition (Kutoš *et al.* 2003; de Almeida Costa *et al.* 2006). The combination of rice (good source of sulfur amino acids but deficient in lysine) and beans (rich in lysine but deficient in sulfur amino acids) provides an excellent balance of amino acids (Bressani and Elias 1968; Marques and Bora 2000; Pires *et al.* 2006; Berrios 2012). The flour of broken rice and beans has similar nutritional values as that of whole beans, and are gluten-free, which is an important characteristic of food products for people suffering from celiac decease. Therefore, flours from bandinha and rice grits could be combined to prepare formulations that could be used to develop value-added, gluten-free foods, such as expanded breakfast cereal-type products.

Extrusion is a high-temperature, short-time cooking process that is used in the fabrication of a wide range of food products, many of which cannot be easily produced by other cooking processes. The extrusion process of breakfast cereals involves the transformation of ingredients under heat, moisture, pressure and shearing into a viscoelastic mass that undergoes a sudden drop in pressure when leaving the extruder; this process allows water to vaporize and the cereal mass subsequently expands (Strahm 1998; Fellows 2000). Expansion, texture and color are important quality properties for the acceptance of expanded extruded products (Patil *et al.* 2007; Berrios 2012). Good degree of expansion is generally desirable for snack products and extruded breakfast cereals. Because breakfast cereals are immersed in an aqueous medium (e.g., milk) upon consumption, these products must have higher apparent density (AD), lower porosity and thicker walls; they must maintain their texture for the longest amount of time possible and must have minimal moisture absorbance (Mercier *et al.* 1998).

The chemical, physical and nutritional properties of extruded products are influenced by certain processing conditions, including extruder screw speed, barrel/die temperatures and feed rate. Raw material characteristics, such as initial moisture content and starch content, among others, also affect the overall quality of the final extrudate. The control of these conditions is of great importance for the development of products with highly acceptable sensory and nutritional qualities (González *et al.* 2002).

Experimental design is a tool based on statistical principles that allows a maximal amount of useful information to be derived from a minimal number of experiments (Neto *et al.* 2002). Therefore, when developing or improving a process or when formulating a novel product, proper experimental procedures must be designed to evaluate the effects of the independent variables on the response or dependent variables (Rodrigues and Iemma 2005).

The objective of this study was to determine the effect of extrusion operating conditions of feed moisture content, barrel/die temperature and feed composition on main quality properties (radial expansion index [EI], protein content and AD) of value-added, gluten-free, expanded snack-type products developed from rice grits and bandinha flour formulations.

MATERIALS AND METHODS

Flour Preparation

Broken grains of rice (grits) and beans (known as "bandinha") used in the study were obtained from the main local rice and bean processing companies Cristal Alimentos and Feijão Barão, Ltd. (Goiânia, GO, Brazil), respectively. In this manuscript, the terms rice and bean will be used interchangeably with "rice grit" and "bandinha," respectively. The rice grits and bandinha were ground to flour using a Willye-type knife mill (Tecnal, model TE-650, Piracicaba, São Paulo, Brazil). The granulometry of ground materials was determined by passing 200 g of flour through a set of vibrating sieves with constant stirring for 10 min. Subsequently, the material that was retained in each sieve and the material that passed through were weighed, and their percentages were calculated. The highly uniform flours from grits and bandinha obtained after sieving were packaged separately in polyethylene bags for preparing the respective formulations, which were subsequently cooked and expanded through a single-screw extruder.

Preparation of Formulations for Extrusion

The initial moisture and protein content (on a dry weight basis, dwb) of the rice grits and bandinha used in the study were 10.4, 7.7, 8.6 and 24.5 g/100 g, respectively. Flours from rice grits and bandinha were mixed in different proportion to generate the different extrusion formulations. The bandinha flour in the formulations varied from 13 to 47%. The feed moisture content varied from 10 to 20 g/100 g (on a wet weight basis, wwb) based on the experimental condition of the study (Table 1). The feed moisture content was adjusted by adding water to the dry mixes and calculated as follows: $Y = (Mf - Mi) \times Ws/(100\ Mf)$, where Y = water quantity to be added (mL), Mf = final sample moisture, Mi = initial sample moisture and Ws = sample weight (g). After adding the amount of water needed for each formulation, the same was mixed for 15 min using a domestic mixer, collected in polyethylene bags and allowed to equilibrate overnight at 10C. Before extrusion, the formulations were remixed at room temperature and samples of the mixes were analyzed for moisture to confirm their moisture content.

Extruder and Processing Conditions

The formulations were processed through an Inbramaq, laboratory size, single-screw extruder model Labor PQ30 (Inbramaq, Machinery Industry, Ltd., Ribeirão Preto, São Paulo, Brazil) equipped with a 5-hp variable speed DC drive unit. The length-to-diameter ratio of the extruder was 20:1, screw compression ratio 3:1 and helix angle 45°. The extruder barrel section consisted of three independent electrically heated and air-cooled zones, and the inner barrel of the extruder had a grooved surface to ensure zero slip at the wall. The temperatures at the first and second zones of the extruder were kept constant (Zone 1 = 40C; Zone 2 = 60C), while the temperature at the third zone varied from 60 to 110C (Table 1). The die consisted of one circular opening 3.85 mm in diameter and its temperature was maintained as the temperature of the third zone. The extruder was fed through a vibratory conical feeder to ensure the material to flow and prevent its accumulation into the feeder. The extruder was run at a constant screw speed and feed rate of 180 rpm and 260 g/min, respectively. These values were selected based on most suitable EI results obtained on a previous study carried out at our laboratory (unpublished data). Extruded material was collected for 5 min under steady conditions. The processed formulations were manually collected in stainless steel trays, cooled down to room temperature and stored in polyethylene bags for further analysis.

Analyses

Moisture content of the samples was determined gravimetrically by drying the materials in a forced-air drying oven at 105C until constant weight according to method 31.1.02 of AOAC (1990). Protein content was determined by the semi-micro-Kjeldahl method according to method 31.1.08 of AOAC (1990) (N × 6.25). AD was determined using a displacement method according to Ramírez and Wanderlei (1997). Results were obtained by the relation between the sample mass (canola seeds) and its volume. All these analyses were run in triplicate. The EI was determined after 30 min of processing (Alvarez-Martinez *et al.* 1988), measuring the diameter of 10 extruded samples with a digital caliper and calculated by the following formula: EI = (sample diameter/matrix diameter)^2; where the matrix diameter was 3.85 mm.

Experimental Design and Data Analysis

A full factorial design (2^3) was used to investigate the effect of bandinha (bean) flour content, die temperature and feed moisture content as the independent or explanatory variables on main quality properties (protein content, AD and the EI) of the extrudates as the response variables, performed as described by Neto *et al.* (2002) (Table 1).

The statistical analysis of the model was performed in the form of analysis of variance (ANOVA). The significance of the regression coefficients and the associated probabilities, p(t), were determined by Student's *t*-test; the second-order model equation significance was determined by Fisher's *F*-test. The variance explained by the model is given by the multiple determination coefficients, r^2. The experimental designs and results analysis were carried out using Statistica

TABLE 1. GRANULOMETRIC ANALYSIS OF THE BROKEN RICE AND BEAN FLOURS

	Particle size (mm)				
Percent flour	>2.19	2.19–0.84	0.84–0.66	0.66–0.50	<0.50
Broken rice	0.00 ± 0.00	61.58 ± 1.07	37.01 ± 0.17	0.53 ± 0.51	0.87 ± 0.50
Bean "bandinha"	3.66 ± 0.32	84.23 ± 0.55	11.43 ± 0.32	0.23 ± 0.06	0.43 ± 0.23

7.0 (Statsoft 1997). This statistical software was also used to draw the presented surface plot with contour layout.

RESULTS AND DISCUSSION

Granulometric Composition of the Grits (Rice) and Bandinha (Bean) Flours

The results obtained from the granulometry evaluation of the broken rice (grits) and bandinha (bean) flours used in the formulation of the feed mixtures fed to the extruder are shown in Table 1. It was observed that 61.58% of the broken rice particles and 84.23% of the bean particles were retained in sieves between 2.19 and 0.84 mm, which indicated that the raw materials had a fairly homogeneous particle size distribution.

Evaluation of the Effect of Processing Variables on Product Quality of Rice and Bandinha-Based Extrudates

The effect of the different independent or explanatory variables on the response variables of protein content, AD and radial EI of the extrudates developed from the different rice and bandinha formulations were determined from the matrix of the experimental design presented in Table 2. The protein content varied from 9.44 to 14.74 g/100 g for formulations containing 13% bandinha flour processed at 85C and 15% feed moisture and 47% bandinha flour processed under the same conditions of temperature and feed moisture, respectively. Because 13 and 47% of bandinha flour were the lowest and highest concentration considered in the factorial design, the presented results indicate that bandinha flour was the major contributor of protein in the formulations. Some of the most important quality parameters of expanded food products, such as breakfast cereals, are related to their expansion, density and hardness as these parameters are directly related to the desirable crunchy/crispy texture of those types of products (Patil *et al.* 2007; Berrios 2012). Additionally, the density of expanded products is an important factor related to their storability. Because lower density relates to lower weight of the material to store and transport, a combination of high expansion and low density is highly desirable in expanded food products, such as extruded breakfast cereals. The values of AD of the different rice and bandinha-based extrudates varied widely from 0.17 to 0.51 g/cm^3 among the different formulations and processing conditions (Table 2). However, AD showed to be more affected by feed moisture than the independent variable of bean flour. As the linear and quadratic regression models were significant for feed moisture, only the linear regression model was significant for bean flour (Table 3). The values of EI showed to be lowest at high bandinha flour content in the mix of 40%, highest

TABLE 2. RESULTS OF THE FULL FACTORIAL EXPERIMENTAL DESIGN FOR PROTEIN CONTENT, APPARENT DENSITY (AD) AND REDIAL EXPANSION INDEX (EI) OF EXTRUDATES MADE FROM RICE GRIT AND BANDINHA (BEAN) FLOUR FORMULATIONS

	Levels of variables in real units					
Trial	Bean flour (g/100 g)	Temperature* (C)	Moisture† (g/100 g)	Protein (g/100 g)	AD (g/cm^3)	EI
1	20	70	12	11.18	0.17	10.68
2	40	70	12	13.83	0.20	9.15
3	20	100	12	10.76	0.17	7.32
4	40	100	12	13.29	0.20	6.06
5	20	70	18	10.43	0.38	6.43
6	40	70	18	13.15	0.40	5.21
7	20	100	18	10.79	0.22	6.61
8	40	100	18	13.19	0.38	4.68
9	13	85	15	9.44	0.17	12.35
10	47	85	15	14.74	0.20	7.73
11	30	60	15	12.83	0.17	8.83
12	30	110	15	12.68	0.17	7.31
13	30	85	10	12.71	0.17	7.41
14	30	85	20	12.02	0.51	5.21
15	30	85	15	13.52	0.20	9.54
16	30	85	15	13.26	0.20	9.64
17	30	85	15	13.15	0.20	9.13
18	30	85	15	13.57	0.21	9.92
19	30	85	15	13.63	0.20	9.68
20	30	85	15	13.46	0.20	8.94

* Temperature at the third zone/die.
† Feed moisture content.

TABLE 3. SIGNIFICANCE OF REGRESSION MODELS USING STATISTICAL ANALYSIS

Independent variables	Estimated effects	Pure error	*t*-value	*P*-value
Effects estimated for protein content				
Intercept	13.4390	0.0752	178.7491	0.0000
Bean flour (L)	2.8155	0.0998	28.2072	0.0000
Bean flour (Q)	−1.0604	0.0973	10.9002	0.0001
Temperature (Q)	−0.5872	0.0973	6.0365	0.0018
Moisture (L)	−0.3894	0.0998	3.9014	0.0111
Moisture (Q)	−0.8660	0.0973	8.9021	0.0003
Moisture*Temperature	0.3380	0.1304	2.5930	0.0487
Effects estimated for apparent density				
Intercept	0.2011	0.0012	165.2817	0.0000
Bean flour (L)	0.0457	0.0016	28.2872	0.0000
Temperature (L)	−0.0280	0.0016	−17.3630	0.0000
Temperature (Q)	−0.0077	0.0016	−4.8945	0.0045
Moisture (L)	0.1783	0.0016	110.3487	0.0000
Moisture (Q)	0.1100	0.0016	69.8848	0.0000
Bean flour*Temperature	0.0330	0.0021	15.6175	0.0000
Bean flour*Moisture	0.0279	0.0021	13.2239	0.0000
Moisture*Temperature	−0.0444	0.0021	−21.0208	0.0000
Effects estimated for expansion index				
Intercept	9.5752	0.1491	64.2009	0.0000
Bean flour (L)	−2.0308	0.1980	−10.2563	0.0002
Bean flour (Q)	−0.8698	0.1930	−4.5073	0.0064
Temperature (L)	−1.2308	0.1980	−6.2157	0.0016
Temperature (Q)	−1.4163	0.1930	−7.3393	0.0000
Moisture (L)	−2.8673	0.1980	−14.4808	0.0000
Moisture (Q)	−1.2146	0.1930	−6.2941	0.0015
Moisture*Temperature	0.7517	0.2586	2.9068	0.0335

Values are significant at the 95.0% level. Only significant linear, quadratic and interaction terms of the equation are reported in this table.

processing temperature of 100C and intermediate feed moisture of 18 g/100 g. On the other hand, the values of EI showed to be highest at the lowest bandinha flour content in the mix of 13%, intermediate processing temperature of 80C and intermediate feed moisture of 15%. This indicated that EI in the developed extrudates was mainly affected by the protein concentration in the formulations, provided largely by bandinha flour, than by the difference in temperature and feed moisture used in the processing of the mixes. Direct-expanded snacks rely on the functional properties of starch for expansion. The bandinha flour, used as the main source of protein, may have acted as diluents of the total starch present in the mixes limiting the expansion of the extrudates containing higher percentage of the bean flour. Similar results were reported by Kannadhason *et al.* (2011) who produced extrudates from formulations containing three different protein levels of 28, 30 and 32 g/100 g. They reported that extrudates produced with lower protein levels exhibited greater expansion.

Protein Content

To quantify the relationship between the dependant and independent variables, regression analysis was performed. If the *t*-value of a coefficient was significant at lower *P*-value, it indicated that term was more important than others in the model and made significant contribution to the dependant variable. Based on the statistical analysis, the following independent variables significantly ($P < 0.05$) affected protein content (Table 2): a linear and a quadratic effect of bean flour, a quadratic effect of temperature, a linear and a quadratic effect of feed moisture, an interactive effect of feed moisture content × temperature. The coefficient of determination (r^2) value was 0.98%, which revealed that there was a strong correlation between variables and indicated that 98% of the changes in protein content could be explained by the model. Also, the ANOVA indicated no lack of fit for this model with $F_{calculated} = 79.03$ for the regression, which was approximately 27 times the F_{listed} value (2.91). Therefore, the model could be considered significant and predictive within the experimental range of data analyzed in the study.

The model for protein content as a function of the variables analyzed is shown below:

$$y = 13.44 + 1.41x_1 - 0.53x_1^2 - 0.29x_2^2 - 0.19x_3 - 0.43x_3^2 + 0.17x_2 \cdot x_3 \quad (1)$$

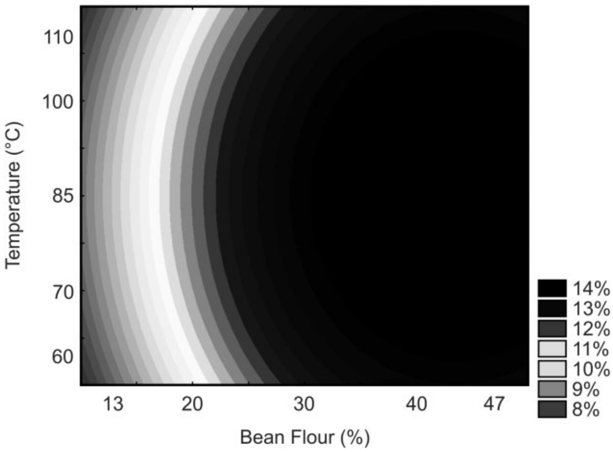

FIG. 1. RESPONSE SURFACE PLOT WITH CONTOUR LAYOUT FOR PROTEIN CONTENT (G/100 G) AS A FUNCTION OF PROCESSING TEMPERATURE (C) AND BEAN FLOUR (G/100 G)

where y = protein content, x_1 = bean flour, x_2 = temperature and x_3 = feed moisture content.

Interpretation of regression equation can be improved by presenting constant values of dependent variables graphically (such as a response surface plot with contour layout) as a function of two independent variables studied over their range of variation, keeping other independent variables constant. Therefore, Figs. 1 and 2 were used to observe clearly the effect of different levels of bean (bandinha) flour in the formulation and extrusion temperature (at the third zone/die) on the protein content of the developed extruded products. It was observed that as the percentage of bean flour increased in the formulations, the protein content in the final extruded product also increased under the independent variable of barrel temperatures (Fig. 1). The lowest protein content was observed on the extrudates processed at the lowest feed moisture content of 10% and temperatures above 100C. Similarly, low protein values were observed at feed moisture content above 18%, over the range of processing temperatures used in the study (Fig. 2). Typically, low feed moisture and high mass temperature increase the degree of cook (Linko 1998). Additionally, the Maillard reactions occur readily when food mixes containing protein component and reducing carbohydrates are extruded at low moisture content (Yokota *et al.* 1987). The mixed formulations extruded at moisture content in the range of 18–20% may have undergone a good degree of cook by a more effective heat transfer. This, in turn, may have influenced the rate of Maillard reactions and result in the observed low-protein content in the extrudates. Additionally, the processing temperature showed to have a significant effect in the quadratic model, indicating that small changes in temperature may largely affect the final protein content of the extrudates. The optimum concentration of protein in the final product was obtained with 30 g/100 g of bean flour, 15 g/100 g feed moisture content and barrel temperature of 80C. Under these processing variables, the final extrudate contained about 13 g/100 g crude protein. Therefore, the developed gluten-free, expanded extruded product may be considered a nutritious, high-protein food.

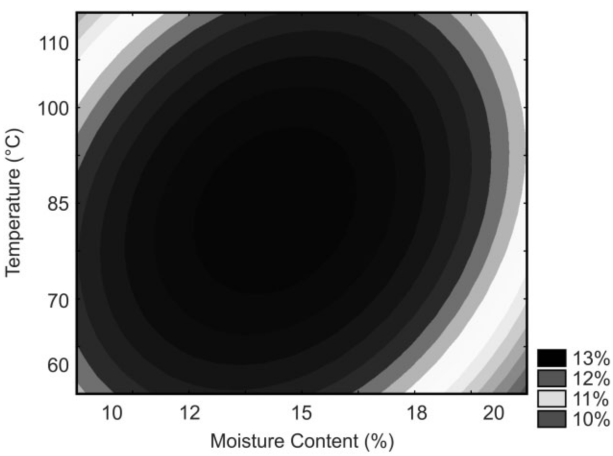

FIG. 2. RESPONSE SURFACE PLOT WITH CONTOUR LAYOUT FOR PROTEIN CONTENT (G/100 G) AS A FUNCTION OF PROCESSING TEMPERATURE (C) AND FEED MOISTURE CONTENT (G/100 G)

Apparent Density

Statistical analysis of the results obtained for AD revealed that all explanatory variables evaluated significantly affected AD with a 95% confidence level. One exception was observed for the variable bean flour, which quadratic effect was not significantly different (Table 3). The following explanatory variables had a significant ($P < 0.05$) effect on increasing AD: a linear effect of bean flour, linear and quadratic effects of moisture content, an interactive effect of linear bean flour × linear moisture content and an interactive effect of linear bean flour × linear temperature. These results demonstrated that an increase in any of the indicated explanatory variables contributed to an increase in the AD of the extrudates. Conversely, linear and quadratic effects of temperature and an interactive effect of linear moisture content × linear temperature had a significant ($P < 0.05$) effect on decreasing AD of the extrudate; that is, an increase in any of the indicated explanatory variables contributed to a reduction in the AD of the extrudates. Low density is a desirable physical attribute to be considered in the development of expanded extruded products. Low density is directly associated to product storability and inversely associated with expansion (Berrios *et al.* 2004; Patil *et al.* 2007).

An ANOVA of the significant variables was performed with $r^2 = 0.94$ and $F_{listed} = 2.95$. The r^2 value indicates that

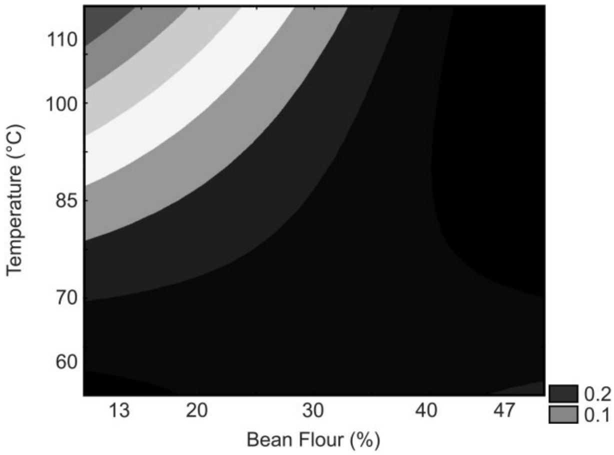

FIG. 3. RESPONSE SURFACE PLOT WITH CONTOUR LAYOUT FOR APPARENT DENSITY AS A FUNCTION OF PROCESSING TEMPERATURE (C) AND BEAN FLOUR (G/100 G)

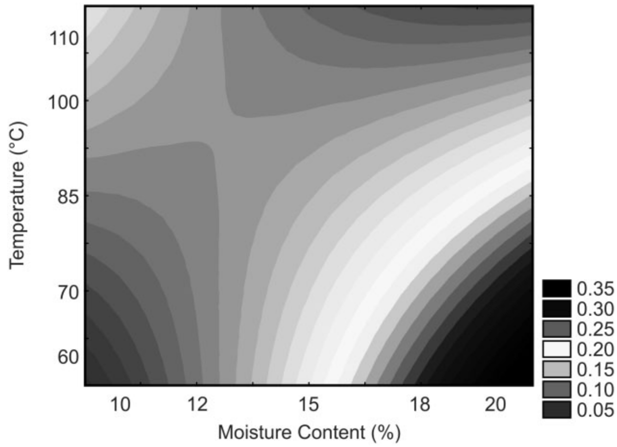

FIG. 4. RESPONSE SURFACE PLOT WITH CONTOUR LAYOUT FOR APPARENT DENSITY AS A FUNCTION OF PROCESSING TEMPERATURE (C) AND FEED MOISTURE CONTENT (G/100 G)

94% of the variability in AD can be explained by the model. The $F_{\text{calculated}}/F_{\text{listed}}$ ratio for the regression was 7.89, indicating an adequate fit of the model, which can thus be used for predictive purposes within the experimental range of data analyzed in the study.

The model for AD as a function of the variables analyzed was:

$$y = 0.20 + 0.02x_1 - 0.01x_2 - 0.004x_2^2 + 0.09x_3 + 0.05x_3^2 + 0.02x_1 \cdot x_2 + 0.01x_1 \cdot x_3 - 0.02x_2 \cdot x_3 \quad (2)$$

where y = AD, x_1 = bean flour, x_2 = temperature and x_3 = feed moisture content.

The response surface plot with contour layout presented in Fig. 3 showed that the independent variable of barrel temperature was the one influencing the most reduction on AD in the final extrudate. Similarly, in Fig. 4, we observed that the independent variable of feed moisture content influenced the most predicted variable of AD. That is, by increasing the temperatures and decreasing the moisture content in the formulations during processing, the AD of the extruded products was reduced to an optimum value of 0.2 g/cm^3. As previously stated, low AD is a desired attribute of expanded extrudates as breakfast cereal-type products.

Expansion Index

Results of statistical analysis demonstrated that the independent variables of bean flour, temperature and feed moisture content had a significant ($P < 0.05$) linear and quadratic effects on reducing the EI of the extrudates (Table 3). The higher value of the predictor variable indicated a larger decreased in the EI of the extrudates. The interactive effect of bean flour × temperature and bean flour × moisture content did not significantly ($P < 0.05$) affect the EI. Only the interactive effect of moisture content × temperature significantly ($P < 0.05$) promoted a higher EI of the extrudates. It was previously indicated that the interactive effect of moisture content × temperature had a significant ($P < 0.05$) affect on decreasing AD of the extrudate (Table 3). High expansion and low density are desirable physical properties of expanded breakfast cereal-type products. These data corroborate the desirable inverse relationship that exists between expansion and density as indicated by previous researchers (Berrios *et al.* 2004; Patil *et al.* 2007).

Based on the ANOVA results, the coefficient of determination (r^2) was 0.90, which indicated that there was a good correlation between variables, as 90% of the changes in the dependent variable of EI could be explained by the model. The $F_{\text{calculated}}$ was seven times greater than the F_{listed}, with a 95% confidence level, indicating that the EI may be estimated as a function of bean flour content, feed moisture content and processing temperature (Eq. 3), within the range of values used in this study.

The model for EI as a function of the variables analyzed was:

$$y = 9.49 - 1.00x_1 - 0.68x_2 - 0.72x_2^2 - 1.02x_3 - 1.34x_3^2 + 0.76x_2 \cdot x_3 \quad (3)$$

where y = EI, x_1 = bean flour, x_2 = temperature and x_3 = feed moisture content.

The contour plots showed that the developed extruded product presented the highest value of EI of 9.5 at the lowest bean flour content in the formulation (Fig. 5). And as the percentage of bean flour in the mixture increased, the

EI decreased in the extrudate. The selected processing temperatures used in this study had a lesser effect on the EI of the extrudates. It is well established that starch has a direct effect on the EI of extruded products (Mercier *et al.* 1998; Patil *et al.* 2007). Rice flour is both a rich source of starchy material and is also an expansion promoting ingredient. In the formulation, the amount of rice grit flour was higher at lower content of bandinha (bean) flour. This may explain the highest EI observed at the lowest content of bean flour. On the other hand, this study contributes to demonstrating that protein is an ingredient that can damper the EI of extrudates (Fig. 5). The extruded product developed in this study presented maximal EI values at feed moisture content below 18% and processing temperatures about 80C (Fig. 6). This observed expansion may have occurred from a decrease in viscosity of the melt, under the processing conditions of the study. This observation goes along with data reported by Dandamrongrak *et al.* (2011), who reported that the optimized conditions for extruded rice and bean snacks were obtained with feed moisture content lower than 17.5 g/100 g. Additionally, previous researchers have indicated that expansion increases with increasing temperature of about 100C when water content is lower than about 19.5 g/100 g, as a result from a decrease in viscosity of the melt (allowing the melt to expand more readily) or from an increase in vapor pressure (Gomez and Aguilera 1984; Paton and Spratt 1984).

CONCLUSIONS

The granulometry test revealed that 61.58% of the broken rice particles and 84.23% of the bean particles were retained in sieves between 2.19 and 0.84 mm, which indicated that the raw materials had a fairly homogeneous particle size distribution for the fabrication of the value-added, expanded breakfast cereal-type products. The statistical analysis revealed that, based on the high coefficient of determination (r^2) values obtained, there was a strong correlation between the independent variables (bean flour content, die temperature and moisture content) and the dependent variables (protein content, AD and EI) under study. The most suitable processing conditions to develop a high quality product were obtained when the bean flour concentration, feed moisture content and temperature at the third extrusion zone/die were 30, 15 g/100 g and 80C, respectively. These processing conditions yielded a desirable crunchy extrudate with a high radial EI and crude protein of 9.5 and 13 g/100 g, respectively, and a low AD of 0.20 g/cm^3. The results of this study showed that it is possible to develop value-added expanded extrudates into high-protein, gluten-free breakfast cereal-type products from broken rice (grits) and bandinha bean flour mixes.

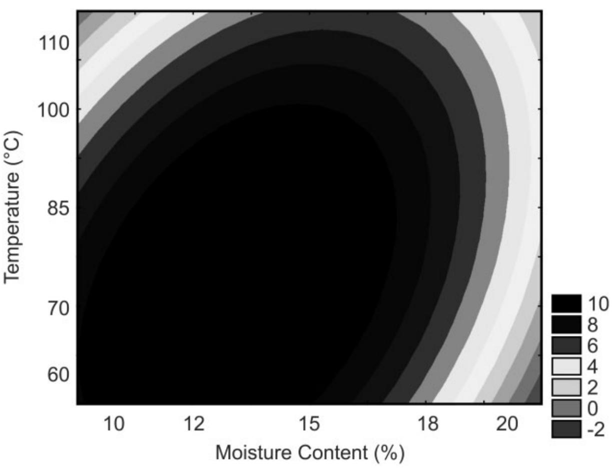

FIG. 6. RESPONSE SURFACE PLOT WITH CONTOUR LAYOUT FOR EXPANSION INDEX AS A FUNCTION OF FEED MOISTURE CONTENT (G/100 G) AND PROCESSING TEMPERATURE (C)

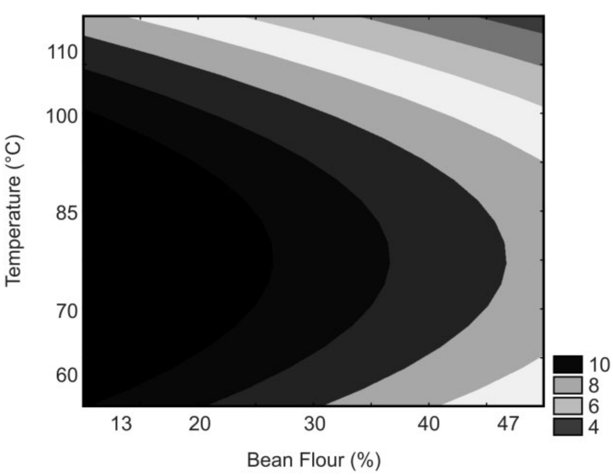

FIG. 5. RESPONSE SURFACE PLOT WITH CONTOUR LAYOUT FOR THE EXPANSION INDEX AS A FUNCTION OF PROCESSING TEMPERATURE (C) AND BEAN FLOUR (G/100 G)

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