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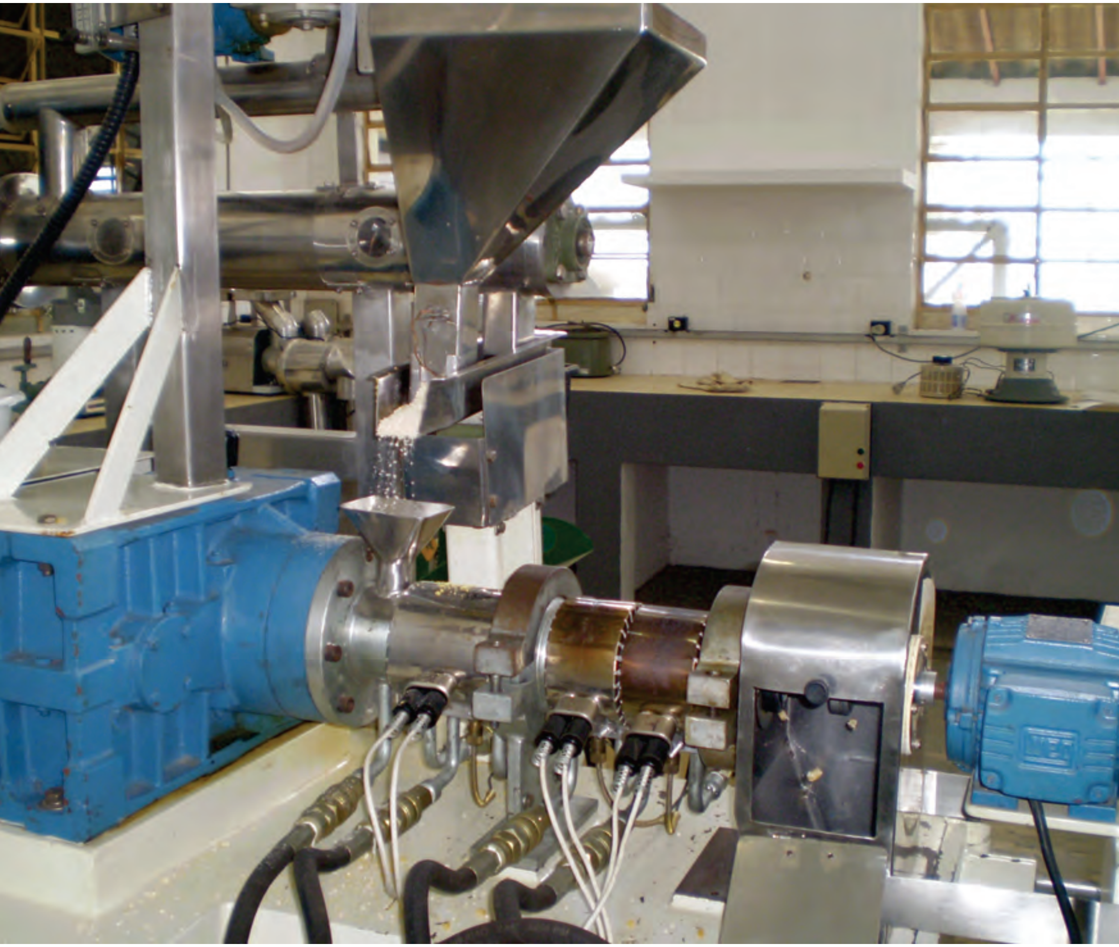

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Development of Extruded Mixtures of Cassava, Green Banana and Brazil Nut Flours

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Abstract

This work aims to optimize the processing conditions for thermoplastic extrusion of blends of cassava flour, green banana flour and brazil nut cake, in order to obtain a pre-gelatinized mixed flour to be used in the preparation of porridge. The flours were optimized using a 2^3 central rotatable composite design with three central points and six axial points. The assays were processed in a single-screw extruder. Two formulations stood out for its nutritional composition, technological properties and sensory acceptance: Formulation 6 (40% cassava flour, 20% green banana flour, 40% brazil nut cake, 14% moisture, temperature 100 °C) and Formulation 16 (40% cassava flour, 30% green banana flour, 30% brazil nut cake, 17% moisture, temperature 80 °C). The results of this study showed that it is possible to develop value-added pre-gelatinized flours into high-protein, 80% acceptability, and satisfactory water solubility and water absorption indexes.

Index Terms: *Manihot esculenta* Crantz, *Bertholletia excelsa* Bonpl., *Musa* spp, extrusion, optimization.

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Desenvolvimento de Misturas Extrudadas de Farinhas de Mandioca, Banana Verde e Castanha-do-Brasil

Resumo

O objetivo deste trabalho foi otimizar as condições de processamento por extrusão termoplástica de misturas de farinhas de mandioca, de banana verde e de castanha-do-brasil, visando à obtenção de uma farinha pré-gelatinizada para consumo na forma de mingau. Para a obtenção das farinhas pré-gelatinizadas, utilizou-se um delineamento do tipo composto central rotacional 2^3, contendo 3 pontos centrais e 6 axiais. Os ensaios foram processados em extrusor monorrosca. Duas formulações destacaram-se em termos nutricionais (elevado teor proteico), tecnológicos e aceitação sensorial: a Formulação 6 (40% de farinha de mandioca, 20% de farinha de banana verde, 40% de farinha de castanha-do-brasil, 14% de umidade, temperatura de 100 °C) e a Formulação 16 (40% de farinha de mandioca, 30% de farinha de banana verde, 30% de farinha de castanha-do-brasil, 17% de umidade, temperatura de 80 °C). Os resultados mostraram que é possível desenvolver farinha pré-gelatinizada com alto teor proteico, 80% de aceitabilidade sensorial e satisfatórios índices de solubilidade e absorção de água.

Termos para indexação: *Manihot esculenta* Crantz, *Bertholletia excelsa* Bonpl., *Musa* spp, extrusão, otimização.

Introduction

Cassava flour (*Manihot esculenta* Crantz) is one of the major derived products of cassava tuberous roots and is widely used throughout Brazil. It is rich in carbohydrates, but its protein has low biological value. Cassava flour has been little explored as an ingredient in preparations of instant foods, such as soups, porridges, instant noodles and foods containing pre-gelatinized flours (LUSTOSA; LEONEL, 2010).

Brazil nut (*Bertholletia excelsa* Bonpl.), also known as *Pará* nut, is one of the main products in the amazon rainforest biodiversity. Its kernel has high biological value proteins, and it is rich in lipids, fiber, vitamin E and minerals such as phosphorus, potassium, magnesium, calcium and selenium. However, despite its great nutrition appeal, brazil nut is still not frequently used by food processing industries (SOUZA; MENEZES, 2004, 2008).

Green banana flour (*Musa* spp) has attracted attention in recent years because of its nutritional value, especially for being high in resistant starch (about 30%). Resistant starch acts as dietary fiber in human body, accelerating intestinal transit time and acting as substrate for bacterial microflora in the large intestine producing a number of beneficial health effects such as blood glucose lowering, hypocholesterolemic action and a protective effect against cancer, among others (GARCIA et al., 2006). From a technological point of view, green banana flour can be widely used in foods, since it does not affect the taste, it increases the amount of fibers, proteins and minerals, and significantly increases the product yield (TORRES et al., 2005).

Extrusion is a process that combines several unit operations including mixing, cooking, shearing, forming and molding. It is a versatile technology, through which it is possible to produce modified or pre--gelatinized starches, widely used to produce instant flour and soups, semi-processed sauces and ready-to-bake mixtures, among others (ASCHERI et al., 2006). Extrusion also confers a beneficial effect on product quality, since it enables mixing different raw materials and nutrients (CARVALHO et al., 2012). This technique facilitates the production of edible mixtures intended for human consumption, such as baby food, instant powder drinks, pre-cooked cereals, etc.

According to Lustosa and Leonel (2010), the enrichment of conventional products that are widely available and well accepted by the population with high nutritional value ingredients is the shortest and most economical way to provide the population with nutritious foods at a price competitive with their counterparts in the food market.

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 of value-added, gluten-free, pre-gelatinized flour developed from cassava, green banana, and brazil nut flours formulations.

Materials and Methods

Cassava flour, purchased from street markets in the city of Belém, PA, and green banana and brazil nut cake, purchased from Olam Amazon oils (JLA Felício Importação and Exportação*,* Rio Branco, AC; industry that partially removes grease from brazil nut by mechanical pressing; brazil nut cake with 56% of lipids), were used in the preparation of pre-gelatinized extruded flour.

Pre-gelatinized extruded flours were processed using different proportions of brazil nuts in the mixed flour (X_1, 13%-47%), temperature in the 3rd extrusion zone (X_2, 47 °C-114 °C) and raw material moisture (X_3, 12%-22%). The flours were optimized using a 2^3 central rotatable composite design (CRCD) with three central points and six axial points (BARROS NETO et al., 1995) and the following analyses' results: water absorption index (Y_1), water solubility index (Y_2), color (Y_3), aroma (Y_4), thickness (Y_5), taste (Y_6) and overall impression (Y_7). The variables levels in the experimental design were defined according to preliminary tests and are shown in Table 1.

Table 1. Variables levels in the experimental design.

Independent variable	Coded and real levels of independent variables				
	- 1,68	-1	0	+ 1	+ 1,68
Amount of brazil nut cake in mixed flour [(1)] (%)	13	20	30	40	47
Moisture (%)	12	14	17	20	22
Temperature (°C)	47	60	80	100	114

[(1)] Mixed flour made from cassava flour (set at 40%) and green banana flour (amount calculated by the difference between 60% and the varying amount of brazil nut cake depending on the experimental design).

The experimental design consisted of 17 experiments (Table 2); the flour mixtures (blends) were homogenized, packed in polyethylene bags, sealed and stored under refrigeration at 7 °C for 24 hours to adjust or balance moisture content before extrusion.

The formulations were processed through an Inbramaq, laboratory size, single-screw extruder model Labor PQ30 (Inbramaq, Machinery Industry Ltda., 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 = 30 °C; Zone 2 = 40 °C), while temperature at the third zone varied from 47 °C to 114 °C. 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 170 rpm and 230 g/min, respectively. Extruded material was collected for 5 minutes under steady conditions.

The extrudates were manually collected, cut into pieces of about 5 cm, spread evenly on trays, and dried in an oven (320-SE, Fanen, São Paulo, Brazil) with air circulation at 50 °C for 20 hours. The extrudates were then ground to particles of about 0.84 mm using a Willye-type knife mill (TE-650, Tecnal, Piracicaba, Brazil) and stored in polyethylene bags for further analysis.

The water absorption index and water solubility index were determined as described by Anderson et al. (1969).

Sensory evaluation included the acceptance test, which was performed using a nine point hedonic scale (STONE; SIDEL, 1993). Forty two tasters of both genders, aged from 18 to 59 years, evaluated the following attributes: color, aroma, thickness, taste, and overall impression. The samples were offered to the tasters in two different sessions on the same day, in the morning and in the afternoon. All 42 panelists evaluated the 17 formulations. For each formulation, porridge was prepared by adding 8% of refined sugar and 13% of pre--gelatinized extruded flour to 1 L of whole milk; the porridge mixture was cooked on the stove top for about 2 minutes. The formulations were served to the tasters in a monadic way at 50 °C.

The experimental design results were analyzed using Statistica 7.0 (STATSOFT, 1997) and analysis of variance (Anova) was used to estimate the statistical parameters and evaluate the fit of the mathematical model (BARROS NETO et al., 1995). Based on overall impression scores, consumers were classified into different groups (preference patterns) using the Euclidean distance and Ward aggregation method and the XLSTAT software, version 5.01. The number of customer segments was determined based on a visual assessment of the dendrogram. The unadjusted data were used and resulted in similar preference segments.

Based on the results obtained, two experiments were selected considering the aspects studied and their interactions. Additionally, the means obtained were compared by the Tukey test at 5% probability, using Statistica 7.0 (STATSOFT, 1997).

The raw cassava, green banana, and brazil nut cake and the two extruded formulations selected were analyzed for water activity, using an AquaLab water activity meter (4TE, Pullman, USA), moisture (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 1997), ash (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 1997), protein (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 1997), lipids (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 1997), and fiber [method for acid detergent fiber, according to Goering and Van Soest (1970)]. The carbohydrate content (%) was calculated as: [100 – (% moisture + % crude protein + % crude lipid + % ash)]. The metabolizable energy was estimated (kcal/100 g) based on the energy nutrients using the Atwater conversion factors: 4 kcal per gram for carbohydrates and proteins, and 9 kcal per gram of fat (ESTADOS UNIDOS, 1963).

The two extruded formulations selected according to the experimental design results were subjected to sensory evaluation for consumer acceptance. One hundred tasters of both genders, aged from 16 to 63 years, evaluated the following attributes: color, aroma, thickness, taste and overall impression, using a 9-point hedonic scale (STONE; SIDEL, 1993) following the same procedures of sample preparation and presentation to the tasters described above. The results were evaluated based on the means obtained, which were compared by the Tukey test at 5% probability using Statistic 7.0 (STATSOFT, 1997).

Results and Discussion

Experimental design: physical and sensory characteristics of extrudates

Table 2 shows the results of water absorption index (WAI), water solubility index (WSI), and the sensory attribute scores of the experiments with pre-gelatinized mixed flour, according to the design matrix.

Water Absorption Index

WAI is directly related to the number of free hydroxyl groups that are available to form hydrogen bonds with water, and it ranged from 2.80 g/g to 6.74 g/g (Table 2) in the different experiments carried out with pre-gelatinized cassava, green banana, and brazil nut flour.

Table 2. Results of the experiments to central composite design for water absorption index variables (WAI), water solubility index (WSI) and sensory attributes evaluated to obtain pre-gelatinized flour mixed.

Experiment	Level of variables in real units [(1)]									
	Nut cake (%)	Moisture (%)	Temperature (°C)	WAI (g/g)	WSI (%)	Color	Aroma	Thickness	Taste	Overall impression
1	20	14	60	3.71±0.11^{d}	20.96±0.12^{fg}	7.19±1.71^{a}	6.81±1.53^{a}	7.02±1.45^{a}	7.17±1.87^{a}	7.21±1.45^{a}
2	40	14	60	5.27±0.18^{bc}	32.16±1.14^{c}	7.62±1.03^{a}	6.86±1.35^{a}	6.84±1.56^{a}	6.48±1.85^{ab}	6.67±1.69 ^{ab}
3	20	20	60	4.94±0.12^{c}	23.66±1.18^{def}	6.95±1.28$^{a b}$	6.40±1.44^{a}	6.81±1.43^{a}	6.67±1.69^{ab}	6.59±1.70 ^{ab}
4	40	20	60	2.80±0.03^{e}	18.69±0.25^{g}	7.43±1.17^{a}	6.74±1.62^{a}	6.74±1.96^{a}	6.90±1.99^{a}	6.84±1.91^{a}
5	20	14	100	4.82±0.07^{c}	23.34±1.15^{def}	7.29±1.29^{a}	6.71±1.43^{a}	6.59±1.90^{a}	6.74±1.65^{a}	6.62±1.82^{a}
6	40	14	100	3.61±0.10^{d}	21.17±0.88^{efg}	7.00±1.66$^{a b}$	6.88±1.55^{a}	6.57±1.68^{a}	7.24±1.49^{a}	7.14±1.33^{a}
7	20	20	100	6.74±0.08^{a}	31.06±1.17^{c}	6.95±1.39$^{a b}$	6.88±1.36^{a}	7.02±1.48^{a}	6.86±1.60^{a}	6.83±1.56^{a}
8	40	20	100	6.23±0.04^{a}	23.89±0.34^{def}	7.52±1.17^{a}	6.81±1.51^{a}	7.10±1.55^{a}	6.90±1.98^{a}	6.93±1.71^{a}
9	13	17	80	5.03±0.21^{bc}	62.23±0.71^{a}	6.07±2.48^{b}	5.98±2.43^{b}	6.95±1.72^{a}	5.45±2.43^{b}	5.60±2.27^{b}
10	47	17	80	3.97±0.05^{d}	24.59±0.95^{de}	7.54±1.28^{a}	7.05±1.56^{a}	6.71±1.79^{a}	6.95±1.70^{a}	6.83±1.75^{a}
11	30	12	80	6.33±0.13^{a}	44.34±3.23^{b}	7.12±1.38$^{a b}$	6.64±1.62^{a}	7.26±1.13^{a}	6.62±1.76^{ab}	6.86±1.31^{a}
12	30	22	80	5.55±0.20^{b}	21.63±1.38^{efg}	7.45±1.36^{a}	6.81±1.47^{a}	7.02±1.55^{a}	7.26±1.30^{a}	7.24±1.28^{a}
13	30	17	47	3.67±0.06^{d}	18.56±0.71^{g}	7.40±0.88^{a}	6.98±1.11 ^{a}	6.76±1.62^{a}	7.00±1.27^{a}	6.93±1.28^{a}
14	30	17	114	5.00±0.44^{bc}	21.32±0.79^{efg}	7.62±1.12^{a}	7.02±1.33^{a}	7.33±1.12^{a}	7.19±1.62^{a}	7.38±1.39^{a}
15	30	17	80	5.53±0.35^{b}	32.05±0.23^{c}	7.38±1.20^{a}	6.88±1.47^{a}	6.90±1.37^{a}	6.76±1.54^{a}	6.88±1.45^{a}
16	30	17	80	4.90±0.06^{c}	25.21±0.63^{d}	7.60±1.08^{a}	7.21±1.14 ^{a}	7.36±0.93^{a}	7.43±1,17^{a}	7.29±1.13^{a}
17	30	17	80	4.73±0.14^{c}	22.97±1.27^{def}	7.50±1.31^{a}	7.12±1.40 ^{a}	7.14±1.28^{a}	7.36±1,41^{a}	7.48±1.08^{a}

[(1)] Average ± standard deviation of 3 replicates to WAI and WSI; average ± standard deviation of 42 reviews for each sensory attribute studied. The same letter in the same column indicates no significant difference at the level of 5% significance.

The results of the statistical analysis of *water absorption index* (Y_1) showed that the linear temperature and the interaction between moisture and temperature were significant at the 95% confidence interval. After exclusion of non-significant variables to perform the analysis of variance (Anova), it was observed that R^2 value decreased significantly from 0.7596 to 0.4249, which is considered an unsatisfactory value to create a predictive mathematical model.

The Tukey test ($p \leq 0.05$) and the CRCD experimental design analysis showed that experiments 7, 8, and 11 had significantly higher WAI values and that experiment 4 had the lowest value, significantly lower than those of the other experiments. According to Silva et al. (2008), pre-gelatinized starches with a good WAI value (greater than 6 g/g) facilitates their interaction with water and lead to weight gain of the products in which they are used increasing their yield, which can be useful in the preparation of baked goods.

Water Solubility Index

WSI is related to the amount of soluble solids in a dry sample, allowing the verification of the severity of extrusion processing (CARVALHO et al., 2002). Therefore, WSI is a parameter that measures the degree of starch degradation; in the present study, it ranged from 18.56% to 62.23% (Table 2).

The results of the statistical analysis of water solubility index (Y_2) indicated that none of the variables of the experimental design (CRCD*)* were significant at 95% confidence interval. Therefore, another analysis was carried out at 90% confidence interval, and it was found that the variables brazil nut cake (Linear) and brazil nut cake (Quadratic) were significant. However, R^2 values were not satisfactory; the value of 0.3504 was found after exclusion of non-significant variables.

According to the mean comparison test (Tukey test at $p \leq 0.05$), experiment 9 had the highest WSI, with low brazil nut cake content (13%) and intermediate values of moisture (17%) and process temperature (80 °C). On the other hand, it was also found that experiments 1, 4, 6, 12, 13 and 14 had the lowest WSI.

Color

The results of the statistical analysis for the variable color (Y_3) indicated that variables brazil nut cake (Linear) and brazil nut cake (Quadratic) were significant at 95% confidence interval and they were subjected to analysis of variance (Anova).

Anova results showed that R^2 value was 0.7908, indicating that 79% of the variability in the variable response can be explained by the model. This value is considered regular to create a useful predictive model.

Moreover, according to Box et al. (1978), in order for a regression to be not only significant but also useful for predictive purposes, the F-calculated/F-tabulated ratio should be greater than three. In the present study, the F-ratio was 3.96, which is considered satisfactory, although very close to 3; the higher the ratio, the better the model.

Based on the results obtained, the data were reevaluated at a 90% confidence interval, and it was found that significant variables were brazil nut cake (Linear), brazil nut cake (Quadratic) and the interaction between brazil nut cake and moisture. The R^2 value obtained was 0.7231, indicating that 72% of the variability in the variable response can be explained by the model. The F-calculated/F-tabulated ratio was 4.42, which is considered good. The p-value, which indicates lack of fit of the model, was 0.5. Although the parameters were not the best, this model can be considered acceptable, and its encoded form can be observed in the equation below:

$Y_3 = 7.44 + 0.27.\ X_1 - 0.23\ X_1^2 + 0.11.\ X_1.\ X_2$, where Y_3 is the attribute *color*, X_1 is percentage of brazil nut cake and X_2 is the percentage of moisture.

Figure 1 shows the response surface plot of the variables Brazil nut cake and moisture, without considering the effect of temperature, since it was not significant.

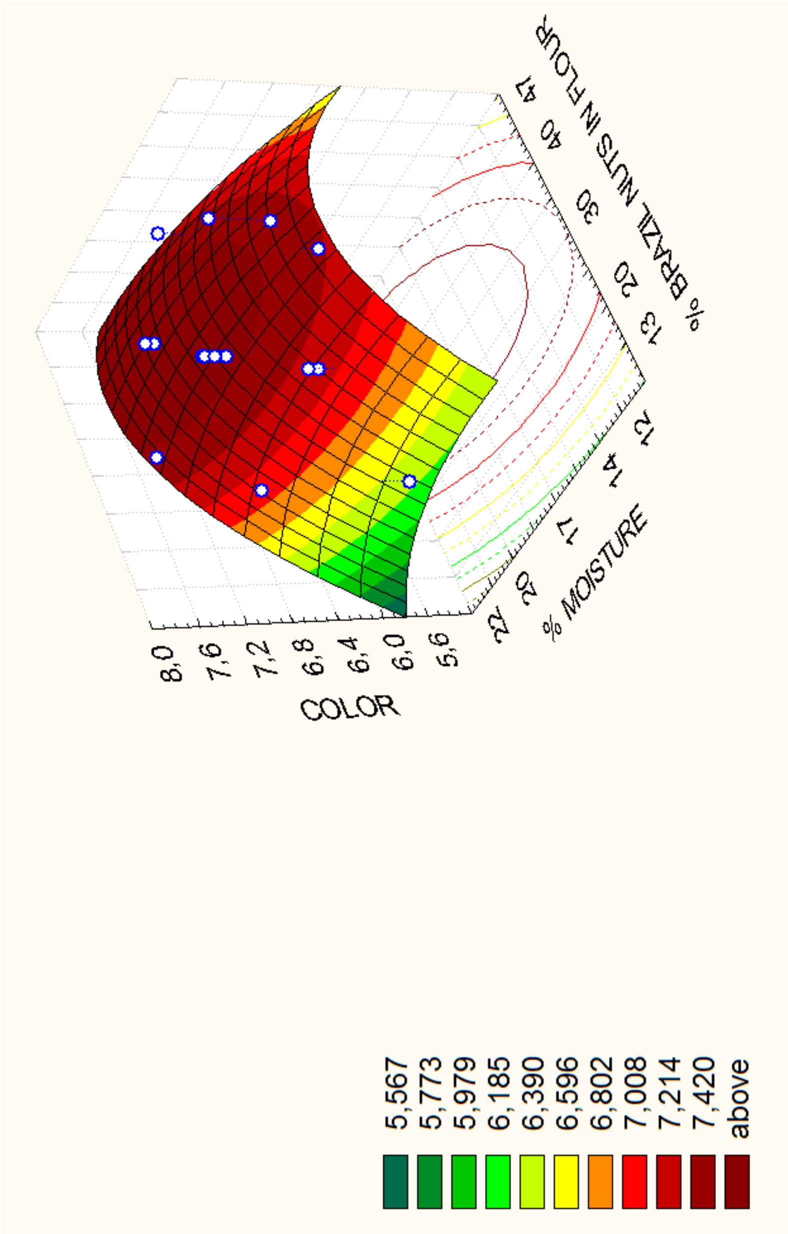

Figure 1. Response surface plot for the variable color depending on brazil nut cake (%) and moisture (%).

It can be seen that the darker area shows the highest consumer acceptance to the attribute color; the variables are positioned above the midpoint. Therefore, in practice, it can be said that the color of the product is improved when the concentration of brazil nut cake is higher than 30% and moisture is higher than 17%. This improvement in color, which is perceived by the tasters, is probably due to the occurrence of Maillard reaction, that gives melanoidins, responsible for the browning of products, giving them the appearance of 'toast'. It is known that Maillard reaction is characterized by reaction of the carbonyl group of reducing sugars with the amine group of proteins, peptides or amino acids, occurring in the presence of heat. Therefore, the higher brazil nut concentration in the formulation of the extrudate, the greater the occurrence of Maillard reaction, promoting higher consumer acceptance to the attribute color.

The Tukey test ($p \leq 0.05$) and the CRCD experimental design analysis showed that experiment 9 (13% brazil nut cake, 17% moisture, 80 °C temperature) had the lowest mean value for the attribute color. However, this experiment was statistically similar to experiments 3 (20% brazil nut cake, 20% moisture, 60 °C temperature), 6 (40% brazil nut cake, 14% moisture; 100 °C temperature), 7 (20% brazil nut cake, 20% moisture; 100 °C temperature) and 11 (30% brazil nut cake, 12% moisture, 80 °C temperature).

Aroma

The results of statistical analysis for the variable aroma (Y_4) were not significant at 95% confidence interval. Therefore, another analysis was carried out at 90% confidence interval, and it was found that variables brazil nut cake (Linear) and brazil nut cake (Quadratic) were significant. However, after exclusion of non-significant variables to perform the analysis of variance (Anova), it was observed that R^2 value decreased from 0.7245 to 0.5453, which is an unsatisfactory value to create a predictive model.

The mean comparison test indicated that only experiment 9 differed from the others, with the lowest mean value. It is worth mentioning that brazil nut cake content in experiment 9 was 13%, the lowest percentage tested. Therefore, it can be concluded that lower content of brazil nut cake negatively affects the acceptance of the final product aroma. It is known that brazil nut cake has a high lipid content and lipids are important as disseminator of aroma and flavor in food. Therefore, the positive effect of increasing brazil nut cake content on the acceptance by the panel is probably due to higher lipid content in formulations which used higher amounts of brazil nut cake.

Thickness

The results of statistical analysis for the variable thickness (Y_5) were not significant at 95% and 90% confidence interval either. The R^2 value obtained in both evaluations was 0.5829.

Similarly, the Tukey test ($p \leq 0.05$) showed no significant difference in any of the experiments, indicating that the attribute thickness is not affected by the variations in brazil nut cake content, raw material moisture and temperature tested during the extrusion process.

Taste

The results of statistical analysis for the variable taste (Y_6) indicated once more that none of the variables were significant at a confidence interval of 95% and 90%. The R^2 value obtained in both evaluations was 0.5873.

The mean comparison test showed that experiment 9 (13% brazil nut cake, 17% moisture, 80 °C temperature) had the lowest mean value for this attribute, but it was statistically similar to experiments 2 (40% brazil nut cake, 14% moisture; 60 °C temperature), 3 (20% brazil nut cake, 20% moisture, 60 °C temperature), and 11 (30% brazil nut cake, 12% moisture, 80 °C temperature).

Overall Impression

The results of statistical analysis for the variable overall impression (Y_7) were not significant at 95% confidence interval, but the analysis at 90% showed that the variable brazil nut cake (Quadratic) was significant. However, after exclusion of non-significant variables to perform the analysis of variance (Anova), it was observed that R^2 value decreased from 0.7021 to 0.4762, which is an unsatisfactory value to create a predictive mathematical model.

The Tukey test ($p \leq 0.05$) showed that experiment 9 had the lowest mean value and differed from experiments 2 and 3.

Consumer Segmentation

The results of statistical analysis (acceptance) for the attributes aroma, thickness, taste and overall impression were not influenced by the variables of the extrusion process of flours. However, multivariate statistical techniques, such as segment analysis, principal component analysis (PCA) and preference mapping, have been widely used (GEEL et al., 2005; WESTAD et al., 2004) offering the advantage of not considering the mean total score of the attribute, but the individual preference of each consumer. Thus, consumer segmentation based on similarities between overall impression scores enabled the identification of four different groups (Table 3). It can be seen that acceptance scores varied very little in the two larger segments (1 and 3). Acceptance mean above 6.0 in these two segments show that there was good acceptance of the samples by 69% of consumers. Consumers in segment 3 “liked very much” the samples (scores between 7.6 to 8.2), except for experiments 9 and 11. However, in segment 1, a mean score above 7.5 was found only for experiments 6 and 11. Segments 2 and 4 grouped the consumers who showed lower acceptance of the porridge; some experiments (2, 4, 5, 8, and 9) were actually rejected, with mean score below 5.0.

Table 3. Average global acceptance of porridge samples as consumer segmentation[1].

Segment[2]	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17
1 (n = 14)	7.4	6.5	6.3	6.6	6.2	7.5	7.0	7.4	7.0	7.0	7.9	7.2	7.2	7.4	6.5	7.2	7.2
2 (n = 08)	6.5	4.8	5.9	4.0	4.3	5.5	5.1	4.8	3.4	4.6	6.1	6.1	5.3	5.8	6.1	6.3	6.8
3 (n = 15)	8.1	8.0	8.1	8.3	7.9	7.8	7.9	8.3	6.0	8.1	6.9	7.9	7.6	8.3	7.7	7.9	8.2
4 (n = 05)	5.4	6.2	4.0	7.8	7.6	6.8	6.0	5.2	4.0	6.2	5.2	7.2	6.8	7.2	6.6	7.4	7.2

[1] E1 to E17 are pre-gelatinized extruded flour mixed.
[2] Segment: segmentation based on similarities between overall impression scores.

Based on sensory evaluation results and technological results obtained, experiments 6 and 16 were selected for further studies, since they were not rejected by consumers and had the highest mean scores among the sensory attributes evaluated (Table 2). In addition, in terms of technology (WAI and WSI), these experiments had satisfactory index values (Table 2) for the pre-gelatinized flours evaluated. Moreover, the physicochemical characterization of the two samples enabled their comparison in terms of nutrition value (protein and lipid levels), given that experiment 6 (Formulation 6) had 40% brazil nut, and experiment 16 (Formulation 16) had 30% of this cake.

Physicochemical characterization of raw materials and pre-gelatinized extruded flours

Table 4 shows physicochemical characterization of green banana, cassava and brazil nut cake and pre-gelatinized extruded flours selected.

The green banana flour values obtained (Table 4) are close to those reported by Borges et al. (2009), who found 4.50% protein, 0.68% lipids, 2.59% ash, 87.92% total carbohydrates and 373.00 kcal/100 g energy value for green banana flour. With regard to crude fiber, Borges et al. (2009) found 1.01%, which is lower than that found in the present study, probably due to the different methods of analysis used in these two studies and to the different varieties of bananas studied.

Table 4. Physicochemical characterization of green banana, cassava, and brazil nut cake and pre-gelatinized extruded flours selected[(1)].

Analyses	Flour				
	Green banana	Cassava	Brazil nut	Pre-gelatinized flour F6	Pre-gelatinized flour F16
Water activity	0.52±0.00	0.27±0.00	0.58±0.00	0.30±0.01[a]	0.28±0.01[a]
Moisture (%)	10.34±0.07	6.98±0.40	2.72±0.16	5.13±0.10[b]	5.52±0.04[a]
Protein (%)	3.29±0.23	0.74±0.04	24.23±0.69	16.20±0.93[a]	10.12±0.98 [b]
Lipids (%)	0.31±0.02	0.26±0.03	56.96±0.26	17.22±0.20[a]	12.29±0.13[b]
Ash (%)	2.13±0.05	0.30±0.02	5.00±0.11	3.03±0.01[a]	2.40±0.02[b]
Crude fiber (%)	2.76±0.13	1.46±0.40	13.12±0.53	5.73±0.19[a]	4.53±0.03[b]
Total carbohydrates (%)	83.93±0.31	91.58±0.63	11.10±0.61	58.43±0.83[b]	69.68±1.08[a]
Energy value (kcal/100 g)	351.68±0.49	371.60±2.59	653.93±1.71	453.46±1.37[a]	429.79±0.75[b]

[(1)]Average ± standard deviation. The same letter in the same line indicates no significant difference at the level of 5% significance.

The cassava flour results obtained are in agreement with those in the literature (CARVALHO et al., 2009; CHISTÉ et al., 2007; SOUZA; MENEZES, 2004), which reports ash levels ranging from 0.38% to 0.93%, lipids from 0.11% to 1.91%, and protein from 0.53% to 2.58%. The fiber content found in the present study is close to that reported by Souza et al. (2008), 1.60% to 2.71%. With regard to moisture and ash levels, the cassava flour evaluated meets the standards set by Brazilian legislation - Normative Instruction nº 52 of November 7th, 2011, Ministry of Agriculture, Supply and Agrarian Reform (Brazil, 2011) – which establishes maximum values of moisture content of 13% and 1.5% ash for the dry-flour group.

Proximate composition of brazil nut cake (Table 4) are within the range found for brazil nut and brazil nut cake by Souza and Menezes (2004), who reported levels of 3.84% of ash, 67.30% of lipids, 14.29% of protein, 3.42% of carbohydrates, 8.02% of total fiber and calories of 676.56 kcal/100 g for brazil nut. As for the brazil nut cake, which was partially defatted by mechanical pressing, these authors reported levels of 8.85% ash, 25.13% lipids, 40.23% protein, 3.37% carbohydrates, 15.72% of total fiber, and calories of 400.60 kcal/100 g (SOUZA; MENEZES, 2004).

The two extruded mixed flour formulations differ from each other in terms of physicochemical characterization. Formulation 6, prepared using 40% of brazil nut cake, results in a formulation with higher protein (16.20%) and lipid (17.22%) content.

In a study on the extrusion of mixtures of brazil nut cake and cassava flour to obtain a product ready for consumption, Souza and Menezes (2008) found protein content ranging from 9.01% to 21.69% and lipid levels of 5.31% to 15.82%, depending on the formulation tested. The values of proteins and lipids obtained in the present study are within or close to the ranges reported by those authors. As for ash and fibers, Souza and Menezes (2008) reported values between 2.61% and 6.60% and 4.29% and 14.05%, respectively. The values of the extruded mixture of green banana flour, cassava flour, and brazil nut cake obtained (Table 4) are close to the lower range values reported by those authors.

The values of carbohydrates (58.43% and 69.68%) and energy density (453.46 kcal/100 g and 429.79 kcal/100 g) of extruded flours showed an energy-rich product that can be used as food to supply shortage of high-energy foods. When we consider the portion consumed for this type of flour, about 30 g, and based on a diet of 2,000 kcal, we can conclude that the pre-gelatinized flours studied represent about 7% of the recommended amount for daily energy needs. Moreover, since the extruded flours developed in this study are intended for consumption in the form of porridge, it is important to mention that the milk to be added in these formulations will contribute to increase the nutritional value of the final product.

The moisture values obtained for the extruded flours, 5.13% and 5.52%, are close to that reported by Carvalho et al. (2013a) in a study on the characterization of pre-gelatinized rice and bean flour (4.84%). Water activity values, 0.30 and 0.28, are within the range found by Ascheri et al. (2006) in a study on pre-gelatinized rice and jabuticaba bagasse flours (0.22-0.79).

Although moisture content is considered an important parameter in food preservation, water activity has been more widely used as a preservation parameter because it better represents the available water that best correlates with food preservation. Since water activity values obtained in the present study were 0.28 and 0.30, extruded green banana flour, cassava flour and brazil nut cake can be classified as a low water activity food. Foods with low water content have moisture levels below 20% and water activity below 0.60, and therefore are microbiologically stable if there is no moisture absorption during storage (CARVALHO et al., 2009; CHIRIFE; BUERA, 1995).

Technological characterization of raw materials and pre-gelatinized extruded flours

Table 5 shows the results of water absorption index and water solubility index obtained from green banana flour, cassava flour and brazil nut cake and pre-gelatinized green banana, cassava and brazil nut flours selected.

Water absorption index indicates the amount of water absorbed by gelatinized granules since they absorb more water than native starch grains due to conformational changes in their structures, such as the changes in the hydrophilic-hydrophobic balance, among others (CARVALHO et al., 2010).

During extrusion process, raw material undergoes several chemical and structural changes, and starch is the component which undergoes the greatest changes. Water absorption index (WAI) and water solubility index (WSI) are parameters that enable to determine the degree of transformation of the starch fraction of the extruded material (CAMIRE, 2000).

Table 5. Results of water absorption index (WAI) and water solubility index (WSI) obtained from green banana, cassava and brazil nut cake and pre-gelatinized green banana, cassava and brazil nut flours selected[(1)].

Flour	WAI (g/g)	WSI (%)
Green banana	3.28±0.12	9.12±0.82
Cassava	5.33±0.09	5.38±0.22
Brazil nut	4.80±0.05	29.85±0.96
Pré-gelatinized F6	4.83±0.02[a]	21.92±1.17[a]
Pré-gelatinized F16	4.94±0.14[a]	18.44±3.13[a]

[(1)]Average ± standard deviation of 3 replicates. For pre-gelatinized flour, the same letter in the same column indicates no significant difference at the level of 5% significance.

According to Table 5, WAI of pre-gelatinized green banana, cassava and brazil nut flours ranged from 4.83 g/g to 4.94 g/g, values close to those reported by Borba et al. (2005) for extruded sweet potato flour (5.0 g/g to 6.2 g/g) and by Carvalho et al. (2013b) in a study on the technological characteristics of extruded rice and bean soup (5.5 g/g). However, they are lower than those reported by Clerici and El-Dash (2008) for extruded pre-gelatinized rice flour (6.97 g/g to 9.02 g/g) and by Silva et al. (2009) for extruded brewers' rice (6.01 g/g to 7.76 g/g).

Water solubility index is related to the amount of soluble solids on a dry sample enabling the determination of the degree of severity of the extrusion processing due to degradation, gelatinization, dextrinization and consequent solubilization of the starch, *i.e.*, it is a parameter which measures the degree of degradation of starch granules (CARDOSO FILHO, 1993; CARVALHO et al., 2010). In the present study, there was a significant increase in WSI values of flours subjected to extrusion process (Table 5). Clerici and El-Dash (2008) carried out a study on the technological characteristics of pre-gelatinized extruded rice flour and found WSI values ranging from 6.78% to 21.53%. On the other hand, Carvalho et al. (2013a), in a study on the characterization of pre-gelatinized rice and bean flour, found WSI values of 24.61%. Filli et al. (2010), in a study on the influence of extrusion parameters on millet and soybean mixed flour, argued that raw materials containing significant amounts of protein can increase WSI because proteins are water soluble molecules, which increases the amount of available particles that will remain in suspension. Martín-Cabrejas et al. (1999) stated that protein denaturation during extrusion process can cause loss of solubility. Gujska and Khan (1991) found that higher extruder barrel temperatures induce protein denaturation leading to a reduction in WSI. Therefore, high solubility index values obtained in the present study (21.99% and 18.44%) suggest low protein denaturation of the mixture, probably due to the mild process temperature conditions (100 °C and 80 °C, respectively). Besides this, the moisture content of the formulations during the extrusion process also influences protein denaturation, since water has a plasticising effect, which leads materials have improved fluidity within the extruder and, therefore, shorter residence with lower denaturation by shear.

Sensory evaluation

The two pre-gelatinized mixed flours selected were again subjected to sensory evaluation by the 100 tasters. The flours selected had similar mean scores in all attributes evaluated and therefore there was no statistically significant difference between them at $p \leq 0.05$. The formulations showed overall impression average of 7.5 (Formulation 6 – F6) and 7.6 (Formulation 16 - F16), and for the evaluated attributes values ranged from 7.6 to 7.8 for F6 and 7.4 to 7.8 for F16. Due to similarity between the samples, consumer preference cannot be predicted; however, the mean scores obtained are considered good, resulting in acceptance above 80% for all attributes.

Conclusion

The results of this study showed that it is possible to develop value-added pre-gelatinized flours into high-protein, 80% acceptability, and satisfactory water solubility and water absorption indexes. The most suitable processing conditions by extrusion to develop a high quality product were obtained when formulations were prepared with 40% cassava flour, 20% green banana flour, 40% brazil nut cake; 14% moisture; 100 °C (last zone of barrel temperature); or 40% cassava flour, 30% green banana flour, 30% brazil nut cake; 17% moisture; and 80 °C (last zone of barrel temperature).

Bibliography

ANDERSON, R. A.; CONWAY, H. F.; PFEIFER, V. F.; GRIFFIN, L. Gelatinization of corn grits by roll and extrusion cooking. **Cereal Science Today**, v. 14, n. 1, p. 4-11, 1969.

ASCHERI, D. P. R.; ANDRADE, C. T.; CARVALHO, C. W. P.; ASCHERI, J. L. R. Efeito da extrusão sobre a adsorção de água de farinhas mistas pré-gelatinizadas de arroz e bagaço de jabuticaba. **Ciência e Tecnologia de Alimentos**, v. 26, n. 2, p. 325-335, 2006.

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. **Official methods of analysis of the Association of Official Analytical Chemists.** Washington, DC: Horwitz W., 1997. 850 p.

BARROS NETO, B.; SCARMINIO, I. S.; BRUNS, R. E. **Planejamento e otimização de experimentos**. 2. ed. Campinas: UNICAMP, 1995. 299 p.

BORBA, A. M.; SARMENTO, S. B. S.; LEONEL, M. Efeito dos parâmetros de extrusão sobre as propriedades funcionais de extrusados da farinha de batata-doce. **Ciência e Tecnologia de Alimentos**, v. 25, n. 4, p. 835-843, 2005.

BORGES, A. M.; PEREIRA, J.; LUCENA, E. M. P. Caracterização da farinha de banana verde. **Ciência e Tecnologia de Alimentos**, v. 29, n. 2, p. 333-339, 2009.

BOX, G. E. P.; HUNTER, W. G.; HUNTER, J. S. **Statistics for experimenters**: an introduction to design, data analysis and model building. Nova York: J. Wiley, 1978. 653 p.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. Instrução Normativa nº 52, de 7 de novembro de 2011. **Diário Oficial da União**, Brasília, DF, 8 nov. 2011. Seção 1. p. 18-20.

CAMIRE, M. E. Chemical and nutritional changes in food during extrusion. In: RIAZ, M. N. (Ed.). **Extruders in food applications**. Boca Raton: CRC PRESS, 2000. p. 127-148.

CARDOSO FILHO, N. **Efeito de algumas variáveis no processo de extrusão e nas características funcionais da farinha de feijão comum**. 1993. 128 f. Dissertação (Mestrado em Tecnologia de Alimentos) - Faculdade de Engenharia de Alimentos, Universidade Estadual de Campinas, Campinas.

CARVALHO, A. V.; VASCONCELOS, M. A. M.; SILVA, P. A.; ASSIS, G. T.; ASCHERI, J. L. R. Caracterização tecnológica de extrusados de terceira geração à base de farinhas de mandioca e pupunha. **Ciência e Agrotecnologia**, v. 34, n. 4, p. 995-1003, 2010.

CARVALHO, R. V.; ASCHERI, J. L. R.; CAL-VIDAL, J. Efeito dos parâmetros de extrusão nas propriedades físicas de extrusados (3G) de misturas de farinhas de trigo, arroz e banana. **Ciência e Agrotecnologia**, v. 26, n. 5, p. 1006-1018, 2002.

CARVALHO, A. V.; VASCONCELOS, M. A. M.; SILVA, P. A.; ASCHERI, J. L. R. Produção de snacks de terceira geração por extrusão de misturas de farinhas de pupunha e mandioca. **Brazilian Journal of Food Technology**, v. 12, n. 4, p. 277-284, 2009.

CARVALHO, A. V.; BASSINELLO, P. Z.; MATTIETTO, R. A.; CARVALHO, R. N.; RIOS, A. O.; SECCADIO, L. L. Processamento e caracterização de snack extrudado a partir de farinhas de quirera de arroz e de bandinha de feijão. **Brazilian Journal of Food Technology**, v. 15, n. 1, p. 72-83, 2012.

CARVALHO, A. V.; BASSINELLO, P. Z.; RIOS, A. O.; FERREIRA, T. F.; CARVALHO, R. N.; KOAKUZO, S. N. Characterization of pre gelatinized rice and beans flour. **Ciência e Tecnologia de Alimentos**, v. 33, n. 2, p. 245-205, 2013a.

CARVALHO, A. V.; BASSINELLO, P. Z.; MATTIETTO, R. A.; RIOS, A. O.; LIMA, A. C. P.; KOAKUZU, S. N.; CARVALHO, R. N. Physicochemical, technological and sensory characteristics of a rice (*Oryza sat*iva L.) and bean (*Phaseolus vulgaris* L.) soup prepared by extrusion. **International Journal of Food Science and Technology**, v. 48, p. 2057-2063, 2013b.

CHIRIFE, J.; BUERA, M. P. A critical review of some non-equilibrium situations and glass transitions on water activity values of foods in the microbiological growth range. **Journal of Food Engineering**, v. 25, n. 4, p. 531-552, 1995.

CHISTÉ, R. C.; COHEN, K. O.; MATHIAS, E. A.; RAMOA JÚNIOR, A. G. A. Estudo das propriedades físico-químicas e microbiológicas no processamento da farinha de mandioca do grupo d'água. **Ciência e Tecnologia de Alimentos**, v. 27, n. 2, p. 265-269, 2007.

CLERICI, M. T. P. S.; EL-DASH, A. A. Technological properties of pre-gelatinized rice flour obtained by thermoplastic extrusion. **Ciência e Agrotecnologia**, v. 32, n. 5, p. 1543-1550, 2008.

FILLI, K. B.; NKAMA, I.; ABUBAKAR, U. M.; JIDEANI, V. A. Influence of of extrusion variables on some functional properties of extruded millet-soybean for the manufacture of 'fura': a Nigerian traditional food. **African Journal of Food Science**, v. 4, n. 6, p. 342- 352, 2010.

GARCIA, J. E.; AYERDI, S. G. S.; AMBRIZ, S. L. R.; PEREZ, L. A. B. Composition, digestibility and application in breadmaking of banana flour. **Plant Foods for Human Nutrition**, v. 61, n. 3, p. 131-137, 2006.

GEEL, L.; KINNEAR, M.; KOCK, H. L. de. Relating consumer preferences to sensory attributes of instant coffee. **Food Quality and Preference**, v. 16, n. 3, p. 237–244, 2005.

GOERING, H. K.; VAN SOEST, P. J. **Forage Fiber Analyses**: Apparatus, reagents, procedures and some applications. Washington, D.C. USDA: Agricultural Research Service, 1970. 19 p.

GUJSKA, E.; KHAN, K. Functional properties of extrudates from high starch fractions of navy pinto beans and corn meal blended with legume high protein fractions. **Journal of Food Science**, v. 56, n. 2, p. 431-435, 1991.

LUSTOSA, B. H. B.; LEONEL, M. Desenvolvimento de misturas instantâneas de mandioca e caseína: efeito do teor de proteína e parâmetros de extrusão sobre a viscosidade. **Ciência e Tecnologia de Alimentos**, v. 30, n. 3, p. 693-699, 2010.

MARTÍN-CABREJAS, M. A.; JAIME, L.; KARANJA, C.; DOWNIE, A. J.; PARKER, M. L.; LOPEZ-ANDREU, F. J.; MAINA, G.; ESTEBAN, R. M.; SMITH, A. C.; WALDRON, K. W. Modifications to physicochemical and nutritional properties of hard-to-cook beans (*Phaseolus vulgaris* L.) by extrusion cooking. **Journal of Agriculture and Food Chemistry**, v. 47, n. 3, p. 1174-1182, 1999.

SILVA, R. F.; ASCHERI, J. L. R.; PEREIRA, R. G. F. A. Composição química de farinhas pré-cozidas por extrusão elaboradas com arroz e café torrado. **Revista do Instituto Adolfo Lutz**, v. 67, n. 1, p. 52-58, 2008.

SILVA, R. F.; ASCHERI, J. L. R.; PEREIRA, R. G. F. A.; MODESTA, R. C. D. Aceitabilidade de biscoitos e bolos à base de arroz com café extrusados. **Ciência e Tecnologia de Alimentos**, v. 29, n. 4, p. 815-819, 2009.

SOUZA, M. L.; MENEZES, H. C. Processamentos de amêndoa e torta de castanha-do-Brasil e farinha de mandioca: parâmetros de qualidade. **Ciência e Tecnologia de Alimentos**, v. 24, n. 1, p. 120-128, 2004.

SOUZA, M. L.; MENEZES, H. C. Extrusão de misturas de castanha do Brasil com mandioca. **Ciência e Tecnologia de Alimentos**, v. 28, n. 2, p. 1-11, 2008.

SOUZA, J. M. L.; NEGREIROS, J. R. S.; ÁLVARES, V. S.; LEITE, F. M. N.; SOUZA, M. L.; REIS, F. S.; FELISBERTO, F. A. V. Variabilidade físico-química da farinha de mandioca. **Ciência e Tecnologia de Alimentos**, v. 28, n. 4, p. 907-912, 2008.

STONE, H. S.; SIDEL, J. L. **Sensory evaluation practies.** 2nd ed. San Diego: Academic Press, 1993. 338 p.

STATSOFT. **Statistic for Windows**. Tulsa, OK, 1997.

TORRES, L. L. G.; EL-DASH, A. A.; CARVALHO, C. W. P.; ASCHERI, J. L. R.; GERMANI, R.; MIGUEZ, M. Efeito da umidade e da temperatura no processamento de farinha de banana verde (*Musa acuminata*, Grupo AAA) por extrusão termoplástica. **Boletim do CEPPA**, v. 23, n. 2, p. 273-290, 2005.

ESTADOS UNIDOS. Department of Agriculture. **Composition of foods**. Washington, D.C., 1963. 190 p. (USDA. Agriculture handbook, 8).

WESTAD, F.; HERSLETH, M.; LEA, P. Strategies for consumer segmentation with application on preference data. **Food Quality and Preference**, v. 5, n. 7-8, p. 681–687, 2004.

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