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Original

Application of roasted rice bran in cereal bars

Aplicação de farelo de arroz torrado em barras de cereais

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Abstract

The objective of this study was to evaluate the viability of using microwave-roasted rice bran as an ingredient in high-fiber cereal bars to obtain a product with good acceptability. The influence of the rice flakes, corn flakes, and roasted rice bran levels on the physical and chemical characteristics of the cereal bars was studied. The overall acceptability of three selected formulations was also evaluated. An increase in the roasted rice bran level in the formulation reduced the force of rupture and water activity, resulted in intermediate density, and caused darkening of the bars. The contents of lipid and total dietary fiber were higher in the formulation with the highest rice bran content, which was therefore classified as functional food. The formulation containing 0.34; 0.32; and 0.34 roasted rice bran, rice flakes, and corn flakes, respectively, seemed to be the best outcome. Cereal bars with roasted rice bran levels between 10 and 20% were accepted by consumers.
Keywords: *Oryza sativa L.; microwave; by-product; product development; dietary fiber.*

Resumo

O objetivo do trabalho foi avaliar a viabilidade da utilização do farelo de arroz torrado, em microondas, como ingrediente de barras de cereais ricas em fibras, para obtenção de um produto com boa aceitabilidade. A influência dos teores de flocos de arroz, flocos de milho e farelo de arroz torrado nas características físicas, químicas de barras de cereais foram estudados. A aceitabilidade global de três formulações selecionadas também foi avaliada. O aumento no teor de farelo de arroz torrado nas formulações reduziu a força de ruptura e atividade de água, a densidade foi intermediária e houve escurecimento das barras. O conteúdo de lipídeos e fibra alimentar total foram maiores nas formulações com maior teor de farelo de arroz, portanto, classificada como alimento funcional. A formulação com a proporção de 0,34/0,32/0,34 de farelo de arroz torrado/flocos de arroz/flocos de milho, se apresentou mais próxima do desejável. Barras de cereais formuladas com teores de farelo de arroz torrado entre 10 e 20% foram aceitas pelos consumidores.
Palavras-chave: *Oryza sativa L.; micro-ondas; subproduto; desenvolvimento de produtos; fibra alimentar.*

1 Introduction

Rice bran contains high levels of lipids and protein and high fiber contents, but it is a product of low commercial value. It is usually used for oil extraction, as an ingredient in animal feed, and as organic fertilizer. In Brazil, it may be found in health food stores as a fiber-rich product. Roasted rice bran is commonly used in multimixtures for low-income families (SILVA; SANCHES; AMANTE, 2006). Due to its high level of fat, rice bran may become rancid (MUJAHID et al., 2003) and therefore the lipase and lipoxygenase must be inactivated soon after milling. Stabilization of the bran by microwave processing does not affect its nutritional value (ABDUL-HAMID et al., 2007; RAMEZANZADEH et al., 2000), but heating for more than three minutes tends to produce a roasted flavor and aroma (RAMEZANZADEH et al., 2000*)*.

The addition of roasted bran to foods causes minor changes in taste, and it can therefore partially replace other flours in bakery products and other formulations. The ability of rice bran fiber to absorb water and oil can contribute to the development of a wide variety of processed products that require such properties; thus, the positive roles of dietary fiber in health promotion and disease prevention, particularly in digestive health, energy balance, cancer, and diabetes and heart and diseases, justify the demand for increased daily intake of dietary fiber (SAUNDERS, 1990; SUN-WATERHOUSE et al., 2010). The increased demand for healthy food, the market for cereal bars, for example, has yielded benefits to the food industry (VILLAVICENCIO et al., 2007). Rice bran could replace ingredients such as corn and rice flakes in bar production providing nutritional and health advantages.

The introduction of an ingredient in a formulation can cause interactions with other components influencing the physical and sensory characteristics of the final product. In new product development, obtaining an optimal formulation may take a long time and entail high costs. Mixture design is used for the development of empirical models to achieve optimal formulations in which the responses depend only on the proportions of the components present in the mixture and not on their absolute amounts (CORNELL, 1990). Therefore,

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the use of a mixture design with varying levels of roasted rice bran, corn flakes, and rice flakes is useful to test the viability of using microwave-roasted rice bran as an ingredient in high fiber cereal bars.

Therefore, the objectives of this study were to formulate well acceptable cereal bars with roasted rice bran and to evaluate the influence of rice flakes, corn flakes, and roasted rice bran levels on the physical and chemical characteristics of the product.

2 Materials and methods

2.1 Roasted bran

The cultivar IRGA 417, processed and provided by EMBRAPA (Goias, Brazil), was used to obtain the bran. The moisture content of the rice bran was adjusted to 21% in order to accelerate enzymatic inactivation (RAMEZANZADEH et al., 2000). Batches of 150 g of the bran were roasted for 12 minutes using a CCE brand model M210 microwave oven with a power of 800 W and a frequency of 2450 MHz. After roasting, the samples were cooled to room temperature for a period of one hour and then vacuum packed in a laminated film (polyethylene/nylon/polyethylene) using a Turbo Vac packer (Turbo Vac, Enfield, Neetherland) to avoid aroma loss.

Roasted rice bran was evaluated chemically and showed a high fiber (38.00 g.100 g^{-1}) content and high levels of lipid (20.31 g.100 g^{-1}) and protein (17.18 g.100 g^{-1}).

The ingredients used to prepare the cereal bars were glucose syrup (Glucogil; Cargil, Guarujá, Brazil), cinnamon (Yoki Alimentos S.A., Paraná, Brazil), and roasted rice bran of IRGA 417 cultivar (Embrapa, Goiás, Brazil). In addition, rice flakes, corn flakes, dried bananas, and baru nut (*Dipteryx alata* Vog) obtained from a local market were used.

2.2 Cereal bar processing

Batches of 400 g of cereal bars were produced. The process was carried out in three stages: weighing of the dry ingredients (roasted rice bran, rice flakes, corn flakes, banana, and Baru nut (*Dipteryx alata* Vog) and cinnamon); heating of the syrup (glucose syrup and guar gum) to 95 °C; and mixing of the dry ingredients with the syrup. The dough was then placed in an acrylic mold which was covered with low-density polyethylene film, and a rolling pin was used to flatten the dough. The mold was left to cool for 1 hour, and the mixture was then packed in low-density and heat-sealed polyethylene bags. The standardized bars were 10 cm long, 3 cm wide, and 1.50 cm thick.

2.3 Experimental design of the mixtures used to obtain the formulation

The concentrations of the test compounds (roasted rice bran, rice flakes, and corn flakes) in the experimental bar formulations were kept within the ranges established in the preliminary tests. In the six experimental cereal bar formulations, roasted rice bran, corn flakes, and rice flakes totaled 30% of the weight, the proportions varied according to the experimental design. The levels of glucose syrup (44%), baru nuts (10%), cinnamon (0.20%), dried banana (13.65%), and guar gum (2%) remained constant.

Based on the above specifications, the pseudocomponents were determined according to Equation 1. Pseudocomponents were used to improve the visualization of the effects the independent variables (roasted rice bran, rice flakes, and corn flakes levels) on the dependent variables (force of rupture, density, lightness, and hue).

$$x_i = \frac{c_i - a_i}{1 - \sum_{i=1}^{q} a_i} \tag{1}$$

where: $0 \le a_i \ge c_i$; $\sum_{i=1}^{q} a_i < 1$; i = 1, 2, 3...., q; x_i = component level in terms of pseudocomponents; c_i = real proportion of the component; and a_i = lower limit of the component concentration.

The experimental design, with the concentration of each ingredient in real values and also in terms of pseudocomponents, is presented in Table 1. Two repetitions of trial 6 (formulations 7 and 8) were introduced to calculate the experimental error and fit of the model, and the experiments were carried out in duplicate (genuine replicates). The order of the trials was randomized, and the Scheffé canonical model for three components was used to fit a polynomial equation to each response by estimating the coefficients of determination (Equation 2).

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 \tag{2}$$

where: Y = dependent variable; β' = estimated coefficient of each linear component and its interactions to develop the predictive model; X_1 = rice bran; X_2 = rice flakes; and X_3 = corn flakes.

The Statistica program, version 6.0 (STATSOFT, 2004) was used to obtain the experimental design and also for data analysis and graph construction.

Physical analyses

Physical analyses of the six experimental formulations and the three locally obtained commercial formulations were carried out (Table 1). The first one was described as traditional, the second as light, and the third as having high fiber content (Table 3).

A TA-XT2i texturometer (Stable Micro Systems, Surrey, England) was used to analyze the force of rupture (Newton - N) of the cereal bars. A small three point bend rig was used and compressed with a speed of 1 mm/s, distance of 15 mm, and force of 0.98 N. The force of rupture was determined at the maximum force of the graph.

A Sony digital camera (DSC - W55) with a resolution of 7.2 mega pixels was used for the color determinations, and digital images of the samples were captured. Three areas of approximately 5 cm × 5 cm were selected for each sample using Microsoft Office Picture Mananger, and the average of three readings for the three areas (9 determinations) was calculated. The images were converted to mean RGB values using the "RGB color converter for BMP images" software (SACHS et al., 2001).

Data were converted to the CIELAB system using a Munsell Conversion software (COLORPRO, 2011) yielding values for lightness (L*) ranging from 100 (light) to 0 (dark) and for hue (h*) ranging from red (0°) to yellow (90°).

To calculate the density, an analytical balance was used to determine the mass, and the volume was determined by the millet-seed displacement method using a graduated cylinder (CAMARGO; LEONEL; MISCHAN, 2008). Water activity of the cereal bars was measured using a water activity meter (AquaLab model CX-2, Decagon Devices Inc., Pullman, WA) under controlled temperature.

2.4 Desirability

Desirability is a tool used to optimize the responses of a factorial design involving the transformation of the dependent variables estimated by statistical models into desired values between 0 and 1 (HARRINGTON JUNIOR, 1965). The response is transformed into a value that represented the most desired value, while that transformed into 0 represented the least desired value and 1, the most desired value. From the statistical models for the physical characteristics generated by the experimental design with the help of the global desirability function and Statistica 7.0 (STATSOFT, 2004), calculations were made to optimize the cereal bar formulations in the intervals used for the independent variables (roasted rice bran, rice flakes, and corn flakes). The goal was to match characteristics of commercial cereal bars.

2.5 Composition and acceptance

Moisture, ash, protein, fat, dietary fiber, and the soluble and insoluble dietary fiber levels of the three selected formulations (F1, F5 and F6) were determined according to the methods of the Association of Official Agricultural Chemists – AOAC (ASSOCIATION..., 2000). The total carbohydrates were estimated by difference, and the reducing sugar content was determined using the Somogyi (SOMOGYI, 1945) and Nelson (NELSON, 1944) method. The chemical analyses were carried out in triplicate. The results were evaluated by the one-way ANOVA and Tukey (5%) considering the sample as the source of variation using Statistica version 6.0 (STATSOFT, 2004).

The three selected cereal bar formulations F1, F5, and F6 were evaluated for overall acceptance in a laboratory scale. The research followed the legal ethical aspects; the project was approved by the Ethics Committee of the Universidade Federal de Goiás (number 181/09). The panel was composed of 51 judges (17 men and 34 women), aged between 20 and 37, with high educational level and previous experience with sensory analysis (94%).

The samples, cut into 3 cm × 3 cm pieces, were served on plastic plates in a sequential monadic manner in a completely randomized design. A 10 cm hybrid hedonic scale, anchored verbally in the middle (neither liked nor disliked) and extreme regions (disliked extremely, liked extremely), was used as suggested by Villanueva, Petenate and Da Silva (2005). The results were evaluated by ANOVA and the Tukey test (5%) considering the samples and panelists as the source of variation using Statistica version 6.0 (STATSOFT, 2004).

3 Results and discussion

3.1 Physical characteristics

The physical properties of the cereal bars formulated using different percentages of rice flakes, corn flakes, and roasted bran were evaluated by ANOVA (Table 2). The mathematical models were significant ($p \leq 0.05$), with coefficients of variation below 7% and coefficients of determination (R^2 adjusted) accounting for 59-99% of the variation. The density model showed significant lack of fit.

The water activity (Aw) of the experimental cereal bars was around 0.55, higher than that of the commercial bars (Table 3).

The samples of cereal bars showed significant variation in the force of rupture (Table 2) (0.72 N to 1.66 N) (Figure 1a).

The force of rupture values found for the cereal bars evaluated in this study were similar to those of commercial products and were closest to that of the high-fiber bar (1.12 N) (Table 3).

Table 1. Experimental design used study the properties of the mixtures of rice bran, rice flakes and corn flakes, in real proportions and in pseudocomponents.

Formulation (Trial)	Proportions of ingredients in the ternary mixture					
	In real concentrations			In pseudocomponents		
	Rice bran (C_1)	Rice flakes (C_2)	Corn flakes (C_3)	Rice bran (X_1)	Rice flakes (X_2)	Corn flakes (X_3)
1	0.66	0.17	0.17	1.00	0.00	0.00
2	0.34	0.34	0.32	0.00	0.53	0.47
3	0.49	0.34	0.17	0.47	0.53	0.00
4	0.49	0.17	0.34	0.47	0.00	0.53
5	0.34	0.32	0.34	0.00	0.47	0.53
6	0.46	0.27	0.27	0.39	0.31	0.31
7	0.46	0.27	0.27	0.39	0.31	0.31
8	0.46	0.27	0.27	0.39	0.31	0.31

Source: STAT SOFT (2004). $X_1 + X_2 + X_3 = 1$ or 100%. C: content of the component in terms of the pseudocomponents. X: real proportion of the component.

Lobato et al. (2012), investigating snack bars with high soy protein and isoflavone, and Dutcosky et al. (2006) investigating cereal bars with high prebiotic fiber content, reported that the greater the amount of (fiber-rich) residue in the cereal bars, the greater the hardness of the bars and the greater their cut resistance. These increases can be explained by the possible compression of the bars due to the presence of fiber residue reducing the amounts of some of the constituents responsible for generating empty spaces or even due to the different granulometry values of the dry constituents.

The commercial cereal bars showed a variation in density between 0.75 and 0.78 $g.cm^{-3}$; and that of the experimental bars varied between 0.44 and 0.79 $g.cm^{-3}$. Thus, the formulations with density close to those of the commercial bars, in the experimental area highlighted in the chart, were F 1 (0.76 $g.cm^{-3}$), F 4 (0.79 $g.cm^{-3}$), and F 2 (0.75 $g.cm^{-3}$). Therefore, the regions between the dotted curves, located between points F 1 and F 4 and F 2, and Y (in pseudocomponent concentrations of 0.36 for rice bran, 0.48 for rice flakes, and 0.12 for corn flakes) were considered to be ideal for the experimental cereal bars with respect to density (Figure 1b).

Lightness (L*) ranged from 31.20 to 37.10, darker than the commercial bars (L* between 40.70 and 42.20). The bars had reddish-yellow hue (h* between 54.20 and 66.20) and were less yellow than the commercial products (from 76.70 to 80.70) (Table 3). The higher the roasted rice bran content, the darker and the more reddish the formulation (lower h*). Therefore, the water activity and density increased and the cereal bar darkened with the increase in the content of roasted rice bran in the formulations.

Focusing on the main interest of this study which was to use rice bran in human nutrition and on the fact that the percentage of roasted rice bran influenced the variability of the physical characteristics, the experimental cereal bar formulations selected were those with the maximum, intermediate, and minimum levels of roasted rice bran. Thus, the bars F1, which contained the highest percentage of rice bran (20%), F5, which had the lowest percentage (10.15%), and F6 with an intermediate content (14.85%), were analyzed for their chemical compositions and overall acceptability.

3.2 Cereal bar desirability

A desirability diagram (Figure 2) was generated for the values of rupture strength, density, and lightness as predicted by their respective models within the range of values for the experimental cereal bars, as compared with the commercial bars.

The diagram shows that the desirability function presented an optimized value in pseudocomponents for the force of rupture, lightness, and density with 42.03% of rice bran (first column), 25.50% of rice flakes (second column), and 32.47% of corn flakes (third column). The experimental formulation 5 was closest to the desirable value since the formulation suggested by

Table 2. Numerical coefficients, adjusted mathematical models and variance analysis parameters for the regression coefficients of the physical properties of the cereal bars.

Variance parameters	Physical properties of the cereal bars[1]			
	Y_1	Y_2	Y_3	Y_4
β_1	0.86	0.76	30.13	54.82
β_2	4.74	3.59	36.03	64.09
β_3	2.07	−1.48	38.68	66.09
β_4	−8.14	−7.06	--	---
β_5	--	4.91	--	---
β_6	−7.18	−1.85		
Model significance (P)	0.01*	0.00**	0.05*	0.04*
Model fit	0.10[ns]	0.00**	0.41[ns]	0.86[ns]
Variation coeficient - CV (%)	6.64	0.81	4.30	3.19
Estimated standard error	0.00	0.00	0.31	0.54
R^2 adjusted	0.92	0.99	0.59	0.63

[1]$Y = \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_1X_2 + \beta_5X_1X_3 + \beta_6X_2X_3$, where Y_1 = force of rupture, Y_2 = density, Y_3 = lightness (L*), Y_4 = hue (h*), X_1 = rice bran, X_2 = rice flakes, X_3 = corn flakes; *Significance at 5% probability of error; **Significance at 1% probability of error; [ns]Not significant.

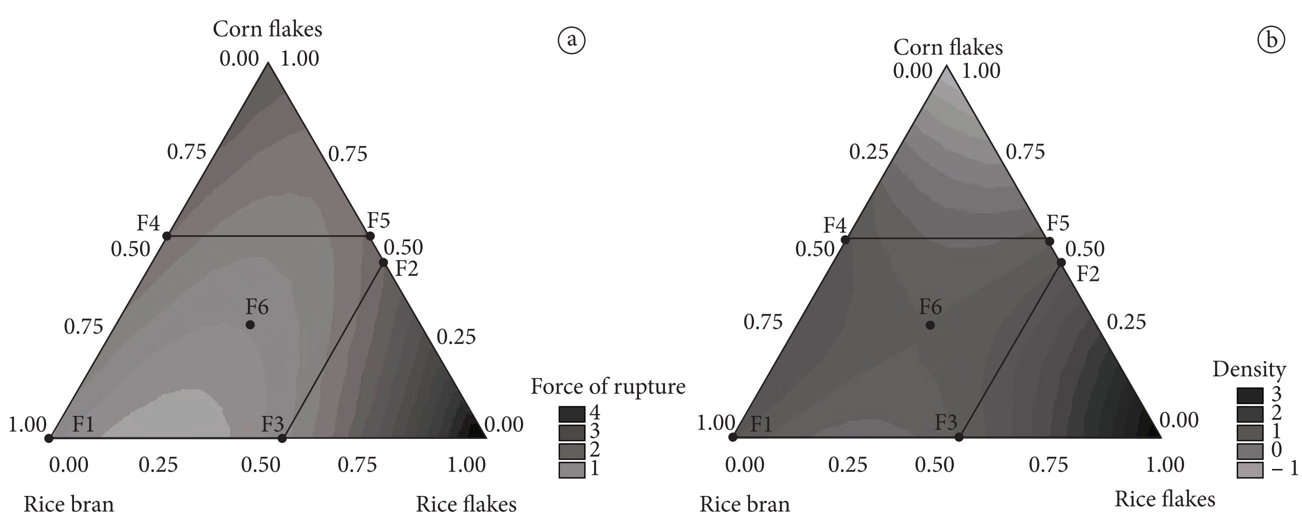

Figure 1. Force of rupture (a) and density (b). Marked area between the experimental points shows the region that could be analyzed.

the desirability function was within the experimental area, but it was not tested because it was not generated by the experimental design.

3.3 Composition and acceptability of the cereal bars

The moisture contents of the formulations were all below 15%, close to that of traditional cereal bars (between 10-15%), as reported by Loverday et al. (2009). The protein content ranged from 6.18 to 7.60 g (100 g)$^{-1}$. F 6 had the lowest protein content (Table 4).

There was a greater variation in lipid content (7.43 to 9.57 g.100 g^{-1}); F1 had the highest lipid content, followed by F6 and F5 (Table 4). Gutkoski et al. (2007) reported lipid contents between 4.94 and 6.57 g.100 g^{-1}, lower than those found in the present study.

The bars had high carbohydrate content (between 67.37 and 72.11 g.100 g^{-1}) due to the high percentage of starch in the cereals and corn glucose in the formulations. The estimated energy value was greatest for F1 (385.95 kcal.100 g^{-1}), which contained the highest level of roasted rice bran, a high- fat ingredient (Table 4). A wide range of variation for energy levels for cereal bars (from 72.8 to 321.70 kcal.100 g^{-1}) has been reported in the literature (GUTKOSKI et al., 2007; DUTCOSKY et al., 2006).

The average values of reducing sugars found in the experimental cereal bars were of 23.31 to 25.39 g.100 g^{-1}, with no variation between the bars (Table 4).

The total dietary fiber content showed an average of 11.44 g.100 g^{-1}, with no variation between the formulations (Table 4). The level of insoluble fiber, predominant in cereal-based products (GUTKOSKI et al., 2007), ranged from 9.40 to 11.57 g.100 g^{-1}; therefore, the three formulations could be considered as fiber-rich product (minimum of 6.00 g.100 g^{-1}), in accordance with Brazilian legislation (AGÊNCIA..., 1998).

The levels of protein and lipid and the total dietary fiber contents were higher in the formulation with the highest rice bran content since the roasted rice bran is an ingredient rich in these components.

All three formulations were accepted. F1, with the highest rice bran content (6.40), was less preferred than F5 and F6 (8.00 and 7.40, respectively), which had the lowest and intermediate levels of rice bran, respectively (Table 5).

Therefore, it can be concluded that it is viable to use roasted rice bran in the formulation of cereal bars. The cereal bars prepared with the minimum (10.15%), intermediate (14.85%), and maximum (20%) levels of roasted rice bran were accepted (mean above 6 in a 10 cm scale). They are foods with high nutritional and quality functional properties and are a viable

Table 3. Force of rupture, density, water activity, lightness and hue of commercial cereal bars (means followed by standard deviations).

Samples of commercial bars	Force of rupture (N)[1]	Density (g.cm^{-3})	Water activity	Lightness (L*)	Hue (h*)
Commercial 1 (Traditional)	0.46 ± 0.10^B	0.75 ± 0.03^A	0.59 ± 0.01^A	41.03 ± 0.30^B	80.72 ± 1.10^A
Commercial 2 (High in fiber)	1.12 ± 0.20^A	0.76 ± 0.80^A	0.61 ± 0.06^A	42.15 ± 0.30^A	76.71 ± 0.50^B
Commercial 3 (Light)	0.64 ± 0.20^B	0.78 ± 0.02^A	0.61 ± 0.00^A	40.67 ± 0.30^B	76.92 ± 0.50^B

[1] Different letters in the same column indicate differences amongst the formulations (Tukey, p ≤ 0.05).

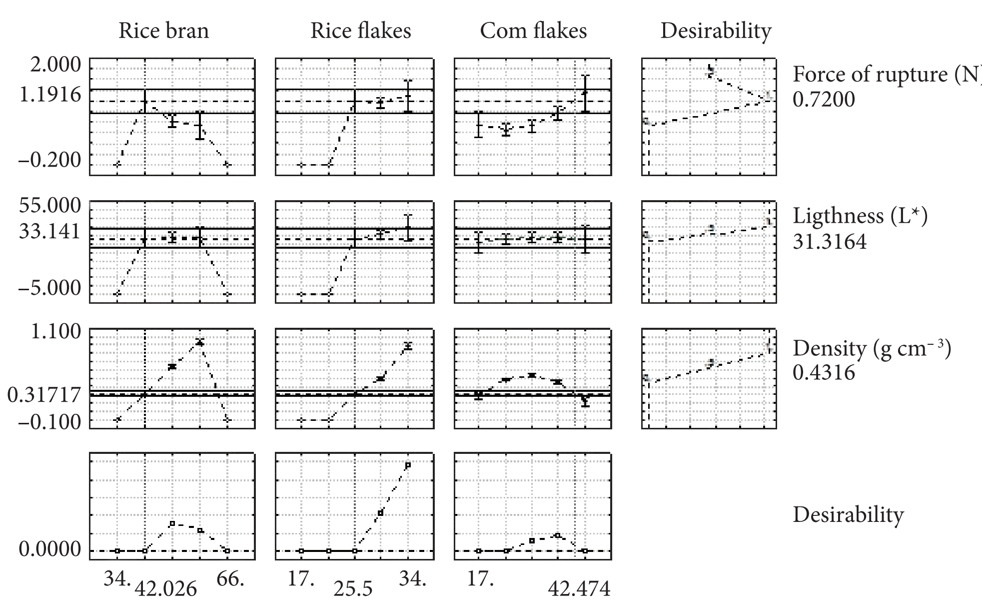

Figure 2. Desirability of a cereal bar in relation to the characteristics of force of rupture, lightness, and density.

Table 4. Chemical composition (g.100 g^{-1}) and energy value of the three experimental formulations of cereal bar[a,b].

Constituent[c]	Formulation 1 (Maximum)	Formulation 5 (Low)	Formulation 6 (Intermediate)
Moisture	9.96 ± 0.30^{B}	10.69 ± 0.07^{A}	9.83 ± 0.22^{B}
Ash	3.68 ± 0.01^{A}	2.61 ± 0.03^{C}	3.06 ± 0.01^{B}
Protein	7.60 ± 0.06^{A}	7.50 ± 0.11^{A}	6.18 ± 0.52^{B}
Lipids	9.57 ± 0.07^{A}	7.43 ± 0.01^{C}	7.79 ± 0.02^{B}
Soluble fiber	0.22 ± 0.06^{A}	2.07 ± 0.78^{A}	0.35 ± 0.10^{A}
Insoluble fiber	11.57 ± 0.19^{A}	9.40 ± 0.54^{B}	10.71 ± 0.52^{AB}
Total dietary fiber	11.79 ± 0.25^{A}	11.47 ± 0.25^{A}	11.06 ± 0.42^{A}
Carbohydrates	67.37 ± 0.28^{B}	70.98 ± 0.39^{A}	72.11 ± 0.18^{A}
Energy value [(kcal (100 g)$^{-1}$][d]	385.95 ± 0.62^{A}	380.79 ± 0.96^{A}	382.40 ± 1.87^{A}
Reducing sugar	25.39 ± 0.10^{A}	23.31 ± 4.77^{A}	23.60 ± 2.00^{A}

Mean in triplicate ± SD. [a] Formulation 1: 20% RB, 5% RF, 5% CF; Formulation 5: 10.15% RB, 9.7% RF, 10.15% CF; Formulation 6: 14% RB, 8% RF, 8% CF, where RB = Rice Bran, RF = Rice Flakes and CF = Corn Flakes; [b] Different letters in the same row indicate differences between formulations (Tukey, p ≤ 0.05); [c] Moisture on a wet basis and other components on a dry basis; [d] Value calculated using the Atwater factors of 4, 4 and 9 kcal / g for protein, carbohydrates and lipids, respectively.

Table 5. Acceptance of cereal bars containing the minimum, intermediate and maximum levels of toasted rice bran[a].

Formulation[b]	Overall acceptance[c]
1	6.35 ± 2.06^{B}
5	7.96 ± 1.51^{A}
6	7.39 ± 1.77^{A}

[a]Mean ± standard deviation of 51 tasters; [b]Formulation 1: 20% RB, 5% RF, 5% CF; Formulation 5: 10.15% RB, 9.7% RF, 10.15% CF; Formulation 6: 14% RB, 8% RF, 8% CF, where RB = Rice Bran, RF = Rice Flakes and CF = Corn Flakes; [c] Different letters indicate difference between the formulations (Tukey, p ≤ 0.05).

alternative to bran. Formulations with up to 15% of rice bran tended to have the highest overall acceptability and showed higher commercial potential, but food industries can use higher levels depending on the interest and desired characteristics.

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