Received: 23 May 2019 | Revised: 17 September 2019 | Accepted: 27 October 2019
DOI: 10.1111/jfpp.14302

ORIGINAL ARTICLE

Journal of Food Processing and Preservation — Institute of Food Science + Technology ifst — WILEY

Optimization of sorghum, rice, and amaranth flour levels in the development of gluten-free bakery products using response surface methodology

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Funding information
Consejo Nacional de Ciencia y Tecnología, Grant/Award Number: 451255

Abstract

Gluten replacement is one of the most challenging issues for the bakery industry. The aim of this work was to optimize rice, sorghum, and amaranth flour levels in the development of gluten-free and additive-free sweet bread of muffin type. Using response surface methodology, optimal values of 50%, 39%, and 11% for rice, sorghum, and amaranth flour, respectively, were obtained. The optimal gluten-free bread was softer, darker, and moister than the whole-wheat control; however, their chemical composition in terms of fat, protein, and carbohydrate content was very similar. In sensory analysis, no significant ($p > .05$) differences were reported between the optimized and the control sweet bread for color and flavor, and both products had positive overall evaluation. Our results suggest a plausible substitution of whole-wheat flour by gluten-free composite flour based on sorghum, rice, and amaranth in preparation of quality gluten-free bakery products with characteristics similar to those of their gluten-containing counterparts.

Practical applications

Nowadays, the demand for gluten-free food products has been increasing. Most commonly, gluten free breads are made with rice, maize, or tapioca flours, either alone or in combination with other gluten-free flours. However, the desirable physical characteristics of these products are normally achieved by the use of hydrocolloids or other additives which may cause low acceptance in consumers. Sorghum, rice, and amaranth grains contain no gluten but can be a rich source of protein, easily digested carbohydrates, lipids, minerals, vitamins, and fiber. The present study provides evidence for a plausible replacement of whole-wheat flour (sorghum, rice, and amaranth) by gluten-free composite flour in preparation of quality, gluten-free and additive-free bakery products with characteristics similar to those of their gluten-containing counterparts.

1 | INTRODUCTION

The increasing number of people diagnosed with coeliac disease, an autoimmune enteropathy characterized by life-long intolerance to gluten proteins present in most cereals, has resulted in a growing demand for gluten-free food (Farage et al., 2017; Giuberti & Gallo, 2018). When these cereals are ingested, a small amino acid sequence found in the prolamin protein fraction causes a chronic inflammatory process which may lead to lesions in the small intestine and a dysfunction in nutrient absorption (Shuppan, Tennis, & Kelly., 2005;

Turabi, Sumnu, & Sahin, 2010). However, gluten has a crucial role in baking since it is the main structure-forming protein present in flour, responsible for the elastic characteristics of dough and the overall appearance and crumb structure of the final bakery product (Gallagher, Gormley, & Arendt, 2004; Ooms & Delcour, 2019). Therefore, gluten replacement is one of the most challenging issues for the bakery industry (Capriles, Santos, & Areas, 2016).

Bakery products, such as bread or cake, are traditionally made with wheat (*Triticum aestivum*) flour. Their gluten-free versions are usually elaborated with rice flour (Gadallah, 2017; Gao et al., 2018) but might exhibit undesirable characteristics, such as low-volume, off-color, and poor crumb structure and texture, due to the low gas retention capacity of rice flour (Torbica, Hadnadev, & Dapcevic, 2010). Thus, in order to obtain quality gluten-free and additive-free bakery products with similar nutritional characteristics to those of their gluten-containing counterparts, carefully designed composite flours from rice and other grains, such as sorghum, amaranth, quinoa, and others, can be used instead of conventional flours (Alvarez-Jubete, Auty, Arendt, & Gallagher, 2010; Moroni, Bello, & Arendt, 2009), aiming at improving not only the baking performance but also the physical and sensory properties of the final gluten-free bakery products (Lamacchia, Camarca, Picascia, Luccia, & Gianfrani, 2014).

Sorghum (*Sorghum vulgare*), as well as rice (*Oryza sativa*) and amaranth (*Amaranthus hypochondriacus*), is cultivated in Mexico but is not usually used for human consumption (Carbajal-García, Rebollar-Rebollar, Hernández-Martínez, Gómez-Tenorio, & Guzmán-Soria, 2018). Sorghum, rice, and amaranth grains contain no gluten but can be a rich source of protein with balanced essential amino acid composition, easily digested carbohydrates, lipids, minerals, vitamins, and fiber (Ahmed, Abdalla, Inoue, Ping, & Babiker, 2014; Alvarez-Jubete, Arendt, & Gallagher, 2009; Oszvald et al., 2009; Turabi et al., 2010), and even cholesterol-lowering nutraceuticals and antioxidants (Ratnavathi & Patil, 2013). Therefore, the nutrimental composition of bakery products can be improved by supplementing wheat flour with these nonwheat flours (Sindhuja, Sudha, & Rahim, 2005).

Response surface methodology (RSM) is a statistical and mathematical technique commonly used for optimal response estimation (Montgomery, 1984; Myers & Montgomery, 1995), including the optimization of ingredient levels in the preparation of bakery products via regression equations which RSM provides (Pizarro et al., 2015). Therefore, the aim of this work was to exploit RSM in the optimization of sorghum, rice, and amaranth flour levels for the development of gluten-free sweet bread of muffin type in order to achieve characteristics as similar as possible to those of sweet bread made with whole-wheat flour without using hydrocolloids or other additives.

2 | MATERIALS AND METHODS

2.1 | Ingredients

All ingredients used in the preparation of the gluten-free sweet bread of muffin type were of Mexican origin. Sorghum grain, which was cleaned and ground to obtain sorghum flour, was provided by "El Brazo" ranch (Valle de Santiago, Guanajuato, Mexico); amaranth flour was purchased from Centro de Valor Agregado de Amaranto S. A. de C.V. (Querétaro, Mexico); and rice flour (Tres estrellas, Mexico) as well as whole-wheat flour (Tres estrellas, Mexico) were bought from a local supermarket. Other commercially obtained ingredients included commonly used Mexican products, such as fresh egg, whole cow milk, cane sugar, vegetable oil, baking powder, and vanilla extract.

2.2 | Preparation

In the preparation of the sweet bread batter, 250 g of gluten-free composite flour (sorghum, amaranth, and rice) was used for the different experimental conditions and 250 g of whole-wheat flour was used for the control condition. A quantity of 150 g of safflower oil was mixed with 125 g of cane sugar in an electric blender (KitchenAid, Mod. MK45SSWH, Mexico) for 6 min at high speed, then 90 g of egg fresh was added, and the beating continued for more 2 min. Subsequently, 100 g of whole milk and 1 g of vanilla extract was added, and the mixture was beaten for 2 min. Then, 250 g of flour and 8 g baking powder were sifted together and added to the mixture, which was again beaten for 2.5 min. After filling the batter into silicone baking cups in 40 ± 1 g aliquots, the muffins were baked in an electric oven (Oster, Mod. TSSTTVSKBT, Mexico) for 10 min at 200°C. Six muffins were obtained for each formulation and subjected to analysis 1 hr after baking.

2.3 | Chemical proximate analysis

Proximate analyses of sorghum, rice, and amaranth flour, as well as the whole-wheat flour and the final bakery products (both optimal and control), were performed in triplicate by the following standard methods (AOAC, 2005): moisture (method 925.09), ash (method 923.03), total crude protein (method 960.52), fat (method 920.39), and total dietary fiber content (method 991.43). Available carbohydrates were calculated (100%—all other components).

2.4 | Evaluation of physical properties

The bakery products were weighed using an electronic balance (Velab, Mod. VE-5000, Mexico) with ± 100 mg precision. The height of the products was measured by an electronic vernier (Control Company, Mod. 3,418, USA) with 0.2 mm precision, from the base of the product up to the highest point of the crust. Color measurements of both bread crust (at the top of the product) and bread crumb (sweet bread cut open just above the silicone cup level) were carried out with a HunterLab colorimeter (Reston, ColorFlexEZ, USA), and the results were expressed in accordance with the CIE-$L^*a^*b^*$ system with reference to illuminant D65 and a visual angle of 10°. The determined parameters were L^* (lightness, L^* = 0 [black] and L^* = 100 [white]), and a^* and b^* (color-opponent dimensions, [a^* negative values = greenness and a^* positive values = redness], [b^* negative values = blueness and b^* positive values = yellowness]). The texture profile analysis (TPA, Bartolozzo, Borneo, & Aguirre, 2016) of the bakery products was measured using a TA-XT2 texture analyzer (Stable Microsystem, United Kingdom), with speed of 1.2 mm/s, a strain of 30% of the original height (4.5 mm), and a 5 s interval between the two compression cycles. The double compression test was performed with a 75 mm diameter aluminum plate (P/75). Each sweet bread was cut above the silicone cup and the upper part was discarded in order to work with the crumb from the center of the bakery product. Hardness, cohesiveness, springiness, and chewiness were calculated from force/deformation profiles (Hleap & Velasco, 2010).

2.5 | Sensory evaluation

A sensory panel was conformed by 50 untrained judges (18–30 years old) who evaluated both the whole-wheat control and the optimized gluten-free bakery product. Four sensory attributes were ranked, namely texture, flavor, color, and general acceptance of the final bakery product. An affective 5-point hedonic scale was used, where 4 stands for "like very much," 3 for "like moderately," 2 for "neither like nor dislike," 1 for "dislike moderately," and 0 for "dislike very much" (Hejrani, Sheikholeslami, Mortazavi, & Davoodi, 2017).

2.6 | Experimental design and statistical analysis

The response surface method applying a mixture design was applied to analyze the data obtained. Mixture design is a type of response surface methodology in which the independent variables are the proportions of mixture components. The effect of these independent variables on the response variable is studied and, subsequently, the response variable is optimized.

The independent variables in this study were the sorghum, rice, and amaranth flour proportions (X_1, X_2, and X_3, respectively). The minimum and maximum values used were set at 15% and 60% for sorghum flour, 15% and 50% for rice flour, and 5% and 25% for amaranth flour, respectively. The values were selected after a thorough literature review (Abdelghafor, Mustafa, Ibrahim, & Krishnan, 2011; Andhikari & Acharya, 2015; Mridula, Gupta, & Manikantan, 2007; Sánchez, González, Osella, Torres, & De la Torre, 2008; Sanz-Penella, Wronkowska, Soral-Smietana, & Haros, 2013; Sindhuja et al., 2005;) and used in the development of gluten-free composite flours which were tested in a pilot baking experiment (Nieto-Mazzocco, Rangel-Contreras, Saldaña-Robles, Abraham-Juárez, & Ozuna, 2018).

The response variables were the height, weight, and moisture of the final bakery product (Y_1, Y_2, and Y_3, respectively), the chromatic coordinates of the bread crust and the bread crumb (Y_4–Y_9, respectively), and the texture profile of the sweet bread, namely its springiness, cohesiveness, chewiness, gumminess, and hardness (Y_{10}–Y_{14}, respectively). A total of 18 experimental runs with different proportions of sorghum, amaranth, and rice flour (Table 1) were carried out in random order and evaluated by sextuplicate.

Both analysis of variance (ANOVA) and regression analysis were performed on the data obtained from the experimental runs, using

TABLE 1 Experimental design for gluten-free composite flour with respective variable levels

Runs	Sorghum flour (%)	Rice flour (%)	Amaranth flour (%)
1	36.76	50.00	13.23
2	50.07	44.92	5.00
3	40.44	34.55	25.00
4	25.01	49.98	25.00
5	60.00	15.01	24.98
6	60.00	27.44	12.45
7	49.91	32.97	17.10
8	51.34	23.65	25.00
9	34.12	43.57	22.30
10	42.90	41.26	15.83
11	58.38	22.11	19.50
12	46.83	36.83	16.33
13	46.83	36.83	16.33
14	50.07	44.92	5.00
15	25.01	49.98	25.00
16	60.00	15.01	24.98
17	36.76	50.00	13.23
18	60.00	27.54	12.47

the Design-Expert 7.0 software (Stat-Ease Inc., USA). Second- and third-order polynomial models were fitted to the data to obtain the regression equations.

The model terms were analyzed to determine their statistical significance through model analysis, lack of fit, and coefficient of determination (R^2) values (Mudgil, Barak, & Khatkar, 2016). A high coefficient of determination (which shows the relationship between the independent and dependent variables) and a nonsignificant lack of fit are adequate to explain the response.

The numerical optimization section of the Design-Expert 7.0 software was used for the optimization of multiple responses. The desired goal for each dependent variable was selected, based on the values obtained by the control condition (whole-wheat sweet bread). For the numerical optimization, all independent variables were kept within their range, while the dependent variables were optimized.

3 | RESULTS AND DISCUSSION

3.1 | Flour composition

The chemical composition of the studied flours is shown in Table 2. The gluten-free flours, as well as the control whole-wheat flour, all presented high levels of carbohydrates. Crucially, amaranth flour proved to be very rich in protein; its protein content being higher than in all other studied flours including the whole-wheat flour. This is particularly important since the protein content of both sorghum and rice flours was only about half the value of the protein content of whole-wheat flour. Therefore, using amaranth flour in the composite should increase the

TABLE 2 Chemical composition of studied flours (whole-wheat, sorghum, rice, and amaranth) and the final bakery products (optimized and control sweet bread)

Matrix	Protein (%)	Fat (%)	Crude fiber (%)	Moisture (%)	Ash (%)	Carbohydrate (%)
Whole-wheat[a] flour	14.01 ± 0.12	1.58 ± 0.05	1.21 ± 0.03	9.01 ± 0.05	1.40 ± 0.01	73.98 ± 0.15
Sorghum[b] flour	6.85 ± 0.10	3.13 ± 0.01	4.00 ± 0.03	9.18 ± 0.03	0.99 ± 0.03	79.83 ± 0.13
Rice[c] flour	7.14 ± 0.08	1.43 ± 0.01	0.68 ± 0.02	10.45 ± 0.03	0.72 ± 0.02	80.25 ± 0.15
Amaranth[d] flour	17.14 ± 0.12	8.02 ± 0.05	2.21 ± 0.02	5.51 ± 0.02	3.61 ± 0.05	65.71 ± 0.16
Optimized sweet bread	6.64 ± 0.04	27.38 ± 0.05	0.35 ± 0.01	10.90 ± 0.04	1.33 ± 0.03	53.71 ± 0.06
Control sweet bread	8.29 ± 0.06	26.44 ± 0.17	0.40 ± 0.02	11.68 ± 0.03	1.56 ± 0.03	52.30 ± 0.18

[a]*Triticum aestivum*.
[b]*Sorghum vulgare*.
[c]*Oryza sativa*.
[d]*Amaranthus hypochondriacus*.

TABLE 3 Regression analysis of second- and third-order polynomial models for various responses

Regression coefficient	Height (cm)	Moisture ($g\ H_2O/g$ W.B)	Crumb lightness	Crumb hardness (kg/ms^2)
*A	+3.25	+0.17	+50.93	+1.23
*B	+3.16	+0.21	+44.31	+1.79
*C	+2.99	+0.16	+102.33	+0.54
*A*B	−0.18	+0.23	+2.01	−0.65
*A*C	+1.62	+0.22	−92.89	−0.49
*B*C	+1.08	−0.017	−136.48	+6.38
*A*B*C			+140.52	−6.83
*A*B (A–B)			+1.82	+1.34
*A*C (A–C)			+41.82	+4.72
*B*C (B–C)			+156.45	−14.54
ANOVA				
Model (*p* value)	***.002***	***.042***	***.041***	***.019***
Lack of fit (*p* value)	.968	.586	.249	.234
R^2	.750	.578	.803	.843

Note: Where: A (Sorghum, %), B (Rice, %), and C (Amaranth, %).
Bold and italic values indicates that these response variables (height, moisture, crumb lightness, and crumb hardness) were significantly ($p < .05$) affected by the proportion variability of sorghum, rice, and amaranth flour levels in the development of the gluten-free sweet bread of muffin type.

protein levels in the final gluten-free bakery product. This, however, may interfere in the technological properties of the final product since, in comparison to wheat flour, gluten-free flour proteins do not have the capacity to form a three-dimensional network and trap the gas. Thus, hydrocolloids, functional ingredients, and other additives can be used to improve the viscoelastic properties of batter for gluten-free bakery products (Djordjević et al., 2018; Gao et al., 2018).

On the other hand, amaranth and sorghum flours turned out to possess higher levels of fat in comparison to rice and whole-wheat flours. Fat contributes to the stability of the bubbles that are generated during baking before starch gelatinization. Therefore, fat is widely linked to structure stability, crumb texture, and sensory characteristics of bakery products (Quiles et al., 2018).

Finally, crude fiber content was highest in sorghum flour, followed by amaranth flour, and then by whole-wheat and rice flours. Fiber represents an important constituent in bakery products and is related to their stability during production and storage. In addition, some fiber characteristics, such as solubility, hydration properties, particle size, and viscosity, can modify the texture of gluten-free bakery products (Djordjević et al., 2018; Gularte, Hera, Gómez, & Rosell, 2012).

Taken together, these proximal analysis results point to the possible advantages and disadvantages of the use of these gluten-free flours, compared to whole-wheat flour, in preparation of nutritious and stable bakery products.

3.2 | Model diagnostics

Out of all 14 response variables studied in this work, only 4 variables (height, moisture, crumb lightness, and crumb hardness) were significantly ($p < .05$) affected by the proportion variability of sorghum, rice, and amaranth flour levels in the development of the gluten-free sweet bread of muffin type. The polynomial models that describe the behavior of these variables, as well as the ANOVAs carried out on the models, are summarizes in Table 3.

3.3 | Effect of variables on bread height

Figure 1.I shows the effect of gluten-free flour levels on the sweet bread height. The product height varied from 3.10 ± 0.27 cm to 3.60 ± 0.16 cm, which was lower compared to the whole-wheat control (4.82 ± 0.22 cm). In general, higher proportions of rice flour and lower proportions of sorghum and amaranth flour resulted in higher products. The tallest product contained composite flour made up with 50%, 37%, and 13% of rice, sorghum, and amaranth flour, respectively. This could be attributed to the fact that sorghum and amaranth flours used in this research contained high amounts of fiber (Table 2), which is closely related to the decrease in height and volume of bakery products (Peressini & Sensidoni, 2009). High contents of fiber in bakery products can cause structural modifications such as a reduction in final volume due to lower retention of carbon dioxide produced by the leavening agents (Quiles et al., 2018). In addition, fiber possesses high water-binding capacity which contributes to a lower height and volume of the final product (Djordjević et al., 2018). In fact, Sanz-Penella et al. (2013) replaced whole-wheat flour by amaranth flour (up to 40 g/100 g) and reported a significant ($p < .05$) decrease in the final bread loaf volume. Similarly, Abdelghafor et al. (2011) reported a highly significant ($p < .001$) decrease in pan bread volume when 10%–20% of whole-wheat flour was substituted by whole and decorticated sorghum flour.

3.4 | Effect of variables on bread moisture

Figure 1.II shows the effect of gluten-free flour levels on the sweet bread moisture. The product moisture varied from 0.15 ± 0.02 g to 0.25 ± 0.01 g of water/g of wet basis (g H_2O/g W.B.), while the whole-wheat control yielded 0.16 ± 0.01 g H_2O/g W.B. In general, higher proportions of sorghum flour and lower proportions of rice and amaranth flour resulted in drier products. The driest product contained composite flour made up with 60%, 28%, and 12% of sorghum, rice, and amaranth flour, respectively. On the other hand, higher proportions of rice flour and lower proportions of sorghum and amaranth flour resulted in moist products. The product with the highest moisture contained composite flour made up with 50%, 37%, and 13% of rice, sorghum, and amaranth flour, respectively.

Bakery products rich in fiber tend to be moister than bakery products made with refined flours (Quiles et al., 2018; Sanz-Penella et al., 2013). In our experiment, the product made with higher proportions of sorghum flour and lower proportions of rice and amaranth flour, and thus higher proportions of fiber (Table 2), was comparable to the control in terms of moisture content. Despite this similarity, gluten-free products might be more prone to staling due to the lack of the gluten network which helps slow down the movement of water from

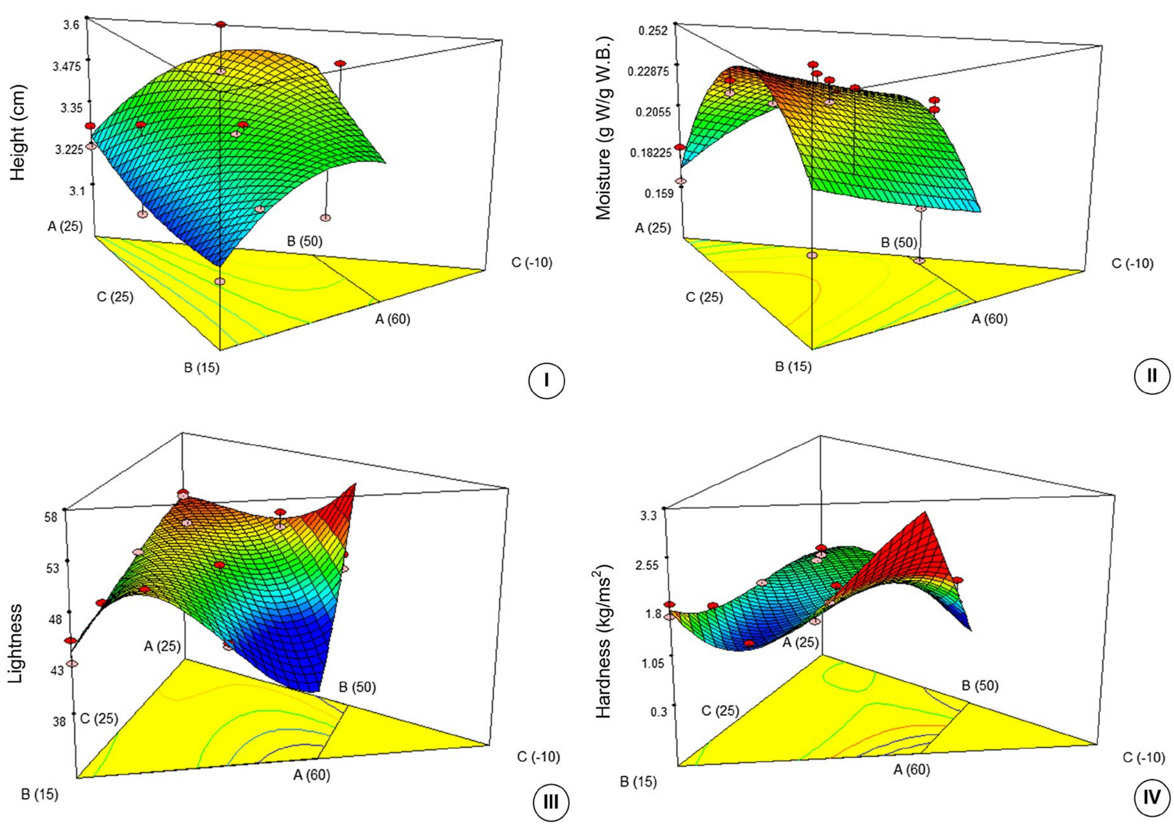

FIGURE 1 Effect of gluten-free flour levels (A: sorghum, B: rice, C: amaranth) on height (I), moisture (II), crumb lightness (III) and crumb hardness (IV) of final product

the bread crumb to the crust during storage (Sciarini, Ribotta, León, & Pérez, 2010). Contrary to our expectations, however, the gluten-free product made with less fiber due to higher proportions of rice flour and lower proportions of sorghum and amaranth flour showed higher values of moisture. We hypothesize this might be due to the fact that this product did not rise properly and resulted in a compact crumb which might have not permitted the excess moisture to evaporate during baking.

3.5 | Effect of variables on crumb lightness

Figure 1.III shows the effect of gluten-free flour levels on the sweet bread crumb lightness. The product crumb lightness varied from 51.18 ± 0.69 to 43.09 ± 0.52, which was darker compared to the whole-wheat control (59.62 ± 0.51). Casas Moreno et al. (2015) reported that madeleines made with sorghum flour were significantly ($p \le .05$) darker than those made with wheat flour, as observed by panelists in sensory analysis of color. In our work, higher proportions of rice flour and lower proportions of sorghum and amaranth flour generally resulted in lighter bread crumb. The product with the highest crumb lightness contained composite flour made up with 50%, 37%, and 13% of rice, sorghum, and amaranth flour, respectively. This is due to the fact that rice flour is obtained from white rice, which has the husk and the outer layer containing pigments removed before milling (Kraithong, Lee, & Rawdkuen, 2018). On the other hand, higher proportions of sorghum and amaranth flour and lower proportions of rice flour resulted in darker bread crumb. The product with the darkest crumb contained composite flour made up with 60%, 25%, and 15% of sorghum, amaranth, and rice flour, respectively. The use of coarse flour from whole sorghum grains, whose pericarp contains tannins and anthocyanins, may have resulted in darker bakery product, since this has been reported when compared to bakery products made with wheat flour or commercial flours (Abdelghafor et al., 2011; Casas Moreno et al., 2015; Nkhabutlane, Rand, & Kock, 2014). Similar results have been reported for amaranth flour (Sanz-Penella et al., 2013).

3.6 | Effect of variables on crumb hardness

Figure 1.IV shows the effect of gluten-free flour levels on the sweet bread crumb hardness. The product crumb hardness varied from 1.06 ± 0.16 kg/ms^2 to 1.92 ± 0.49 kg/ms^2, while the whole-wheat control yielded 1.54 ± 0.10 kg/ms^2. In general, higher proportions of sorghum flour and lower proportions of rice and amaranth flour resulted in softer crumb. The product with the softest crumb contained composite flour made up with 50%, 33%, and 17% of sorghum, rice, and amaranth flour, respectively. Gluten-free bread-like products made mainly with rice flour can often present higher crumb hardness when compared to standard wheat bread due to their complex formulation mainly based on carbohydrates and their lack of gluten (Matos & Rosell, 2011; Salas-Mellado & Haros, 2016). Gluten proteins (monomeric gliadins and polymeric glutenins) are responsible for cohesiveness, elasticity, viscosity, and extensibility of dough, which are important in the formation of a stable three-dimensional network that traps gas during fermentation and baking (Gallagher et al., 2004; Ooms & Delcour, 2019). Therefore, the absence of these proteins in common gluten-free bakery products, such as those based on rice flour, results in more compact crumb containing less trapped gas due to the lack of stable three-dimensional networks (Matos & Rosell, 2011; Salas-Mellado & Haros, 2016).

On the other hand, the inclusion of sorghum and amaranth flour in the composite can result in softer bakery products (Calderón de la Barca, Rojas-Martínez, Islas-Rubio, & Cabrera-Chávez, 2010; Mridula et al., 2007). Mridula et al. (2007) reported that biscuits elaborated with 30%–40% of sorghum flour level increased in hardness, but then, a decrease in hardness was observed at 50%–60% of sorghum flour level. Similarly, Calderón de la Barca et al. (2010) reported that cookies made with amaranth flour were significantly ($p < .05$) softer that the control made with rice flour (10.88 N and 66.84 N, respectively). The softness of bakery products made with higher concentration of some gluten-free flours, such as sorghum or amaranth flour, could possibly be attributed to the higher proportion in fat content in comparison to rice and whole-wheat flours (Table 2).

3.7 | Optimization of variables

Numerical optimization of processing variables was obtained after assigning certain constraints on dependent variable (height: 3.12–4.82 cm; moisture: 0.15–0.24 g H_2O/g W.B.; crumb lightness: 51–59, and crumb hardness: 1.06–1.54 kg/ms^2). Optimization of the gluten-free flour levels was carried out using Design-Expert 7.0 software, yielding the optimal values of 50%, 39%, and 11% for rice, sorghum, and amaranth flour, respectively.

TABLE 4 The values of response variables for the optimized gluten-free sweet bread of muffin type and the control

	Control sweet bread	Optimized sweet bread
Height (cm)	4.82 ± 0.08	3.46 ± 0.05
Weight (g)	36.26 ± 0.42	36.95 ± 0.61
Moisture (g W/g W.B)	0.16 ± 0.01	0.23 ± 0.01
L^* (crust)	61.06 ± 1.42	46.43 ± 1.76
a^*	11.06 ± 1.35	17.65 ± 1.07
b^*	33.56 ± 3.14	37.77 ± 1.16
L^* (crumb)	59.62 ± 0.51	49.54 ± 1.00
a^*	7.89 ± 0.10	7.25 ± 0.15
b^*	29.61 ± 0.28	28.48 ± 0.28
Hardness (kg/ms^2)	1.54 ± 0.09	1.18 ± 0.15
Springiness	0.78 ± 0.02	0.70 ± 0.04
Cohesiveness	0.51 ± 0.01	0.51 ± 0.04
Chewiness (kg)	0.62 ± 0.04	0.47 ± 0.08
Gumminess (kg/ms^2)	0.79 ± 0.05	0.67 ± 0.14

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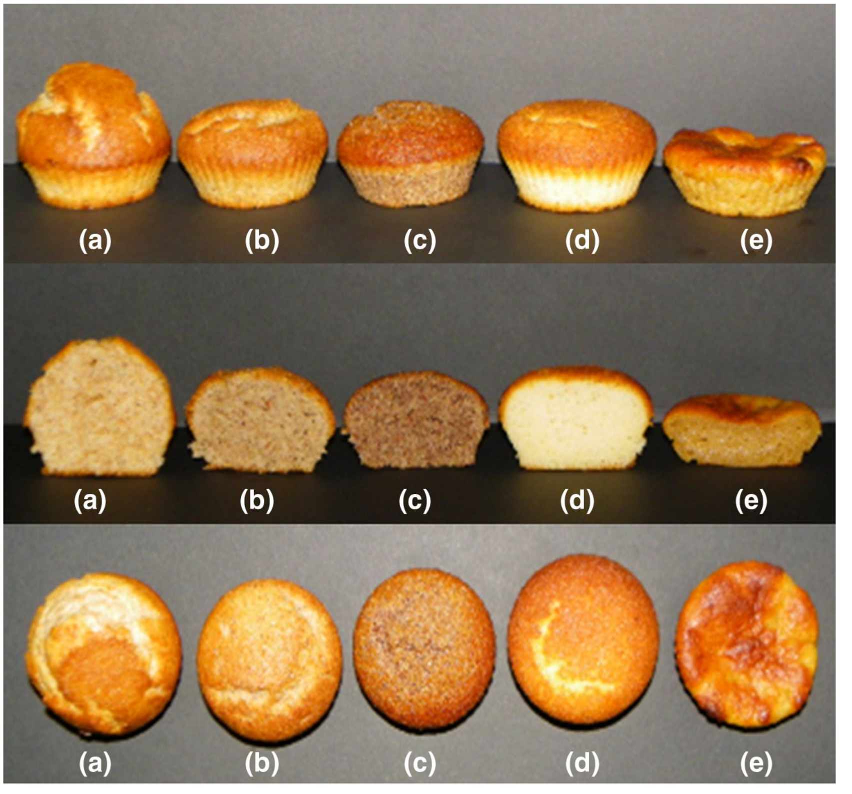

FIGURE 2 Images of (a) control sweet bread, (b) optimized product made with composite flour, and final products in which 100% of whole-wheat flour would be substituted by (c) sorghum flour, (d) rice flour, and (e) amaranth flour

3.8 | Model verification

In order to verify the predictions of the models, a confirmative test was carried out using the optimal levels of independent variables predicted by the models and comparing them to the actual values obtained from the optimized bakery product. The actual values (height: 3.46 ± 0.05 cm; moisture: 0.23 ± 0.01 g H_2O/g W.B.; crumb lightness: 49.54 ± 1.00) were slightly lower than the predicted values (height: 3.53 cm; moisture: 0.22 g H_2O/g W.B.; crumb lightness: 51.10), except for crumb hardness which was slightly higher (1.18 ± 0.15 kg/ms^2) than the predicted value (1.10 kg/ms^2). Nevertheless, the predicted and actual values of these variables are very similar. Thus, the confirmative test validated the experimental results as well as the regression model.

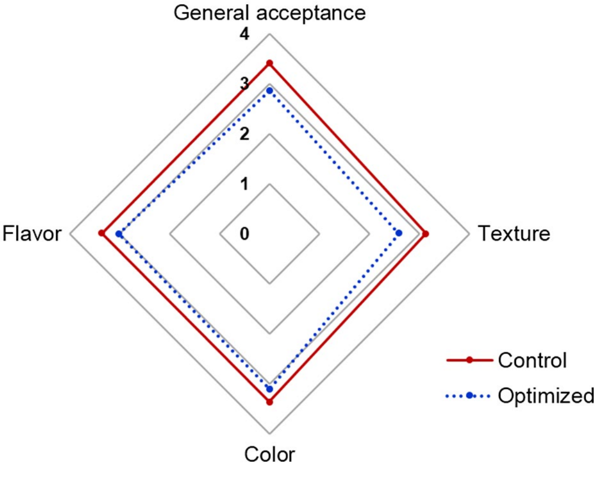

FIGURE 3 Sensory attributes of control and optimized sweet bread of muffin type

3.9 | Characterization of control and optimized gluten-free bread

The values of response variables for the optimized gluten-free sweet bread of muffin type and the control are summarized in Table 4. The optimized product showed higher moisture content (0.23 ± 0.01 g H_2O/g W.B.) than the control whole-wheat sweet bread (0.16 ± 0.01 g H_2O/g W.B.). The optimized product also yielded softer crumb than the control (crumb hardness values of 1.18 ± 0.15 kg/ms^2 and 1.54 ± 1.09 kg/ms^2, respectively). However, the other textural parameters (springiness, cohesiveness, chewiness, and gumminess) were similar for the optimized and the control product.

High moisture content and a soft crumb are desirable characteristic for muffin-type products (Bartolozzo et al., 2016). The optimized product was also generally darker than the control, both in the crust (L^* value of 46.43 ± 1.76 and 61.06 ± 0.42 for the optimized and control product, respectively) and the crumb (49.54 ± 1.00 and 59.62 ± 0.51, respectively). In many countries, consumers associate dark color of bread with health benefits, since it is common in rye-based breads and pumpernickel or dark bran muffins (Casas Moreno et al., 2015; Gosine & McSweeney, 2019).

As is made evident in Figure 2, the control sweet bread (a) yielded more height than the optimized product made with composite flour (b), as well as those final products in which 100% of whole-wheat flour would be substituted by sorghum flour (c), rice flour (d), or amaranth flour (e). However, in terms of crust formation and color difference, the optimized product (b) is visually very similar to the control (a). Moreover, the proximal analysis of the final products revealed that the chemical composition of the optimized gluten-free sweet bread was very similar to that of the control, with the differences in composition being smaller than 2% (Table 2).

Figure 3 shows the results of the four sensory parameters evaluated in the bakery products. For color and flavor, no significant ($p > .05$) differences were reported by the panelists between the optimized and the control sweet bread. Although the general acceptability and the texture of the optimized product received slightly lower marks than the control, both products had relatively positive overall evaluation (Figure 3).

4 | CONCLUSIONS

RSM was successfully used for the optimization of gluten-free flour levels (sorghum, rice, and amaranth) in the preparation of gluten-free sweet bread of muffin type. The changes in proportion of sorghum, rice, and amaranth flours in the bread formulation had a significant effect ($p < .05$) upon the height and moisture of the final product, and on the color and hardness of the crumb. The results of our research suggest a plausible substitution of whole-wheat flour by gluten-free composite flour based on rice, sorghum, and amaranth in preparation of quality, gluten-free and additive-free bakery products with characteristics similar to those of their gluten-containing counterparts.

ACKNOWLEDGEMENTS

The author Elizabeth Nieto-Mazzocco would like to thank CONACYT Mexico for the concession of the 2016 National Scholarship No. 451255. The authors would also like to thank Stanislav Mulík, MA (Applied Linguistics), for his valuable contribution in writing the English version of this paper.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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How to cite this article: Nieto-Mazzocco E, Saldaña-Robles A, Franco-Robles E, Rangel-Contreras AK, Cerón-García A, Ozuna C. Optimization of sorghum, rice, and amaranth flour levels in the development of gluten-free bakery products using response surface methodology. *J Food Process Preserv*. 2019;00:e14302. https://doi.org/10.1111/jfpp.14302