Original Research Article

FOOD SCIENCE AND TECHNOLOGY INTERNATIONAL

Characteristics of biscuits containing different proportions of whole mung bean, wheat and rice brown flours

Larissa Lages Rodrigues[1], Jorge Minoru Hashimoto[2], Elizabeth Harumi Nabeshima[3], Fernanda de Oliveira Gomes[1], Jurandy do Nascimento Silva[4] and Kaesel Jackson Damasceno E Silva[2]

Abstract

A simplex-centroid design was used to evaluate the effect of proportions (0 to 100%) of whole wheat flour (WWF), whole mung bean flour (WMF) and whole rice flour (BRF) on the quality of cookies savory. The dough cut in the shape of a disks (37 mm × 2 mm) showed a 13% retraction in diameter when they contained exclusively WWF, it was less intense (5%) with BRF and null (0%) with WMF. The dough expansion occurred only vertically, the thicknesses of the WWF, WMF and BRF biscuits were 5.33, 2.79 and 2.13 times greater than the initial dough height, respectively. This characteristic showed high correlations with volumetric expansion (r = 0.95), specific volume (r = 0.90), hardness (r = 0.92), fracturability (r = 0.93) and spread factor (r = –0.96). BRF increased the value of the color difference of the biscuits up to 17.70, the effect of WMF was smaller (6.51). Only the radial expansion index correlated with the trough (r = 0.76), final viscosity (r = 0.79) and set-back (r = 0.77) parameters. Considering the main desirable physical characteristics in savory biscuits, the highest global desirability obtained was for the proportion of 49% WWF, 24% WMF and 27% BRF.

Keywords

Bakery products, simplex-centroid, cookie, whole flour, rheology

Date received: 23 March 2022; accepted: 1 August 2022

INTRODUCTION

Food products containing whole wheat flour (WWF) are more nutritious than the corresponding refined flour, with higher levels of minerals, vitamins, proteins, fats, fibers and phytochemicals (Doblado-Maldonado et al., 2012; Ragaee et al., 2012), which are beneficial to health, helping to prevent constipation, coronary heart disease, diverticulitis, ischemia, appendicitis, diabetes and obesity (Kumar et al., 2011; Seal and Brownlee, 2010). But few studies used high percentages of WWF in the production of cookies: Inyang et al. (2018) replaced 0, 25, and 50% of WWF with 25% of acha and/or kidney bean flours, Kumari et al. (2020) replaced 0, 10, 20 and 30% with pumpkin seed flour, and Protonotariou et al. (2016) evaluated 4 types of micronized WWF to replace conventional WWF in 0, 18.5, 30, 50, 80 and 100%.

The USDA (2000) emphasizes that at least 50% of all grain portions eaten should be whole grains. According to Kyro et al. (2012) less than 65% of the Scandinavian

[1]Department of Nutrition, Federal University of Piauí (UFPI), Teresina, PI, Brazil
[2]Brazilian Agricultural Research Corporation Mid-North (Embrapa Meio-Norte), Teresina, PI, Brazil
[3]Institute of Food Technology (ITAL), Campinas, SP, Brazil
[4]Federal Institute of Piauí (IFPI), Teresina, PI, Brazil

Corresponding author:
Jorge Minoru Hashimoto, Brazilian Agricultural Research Corporation Mid-North (Embrapa Meio-Norte), Avenida Duque de Caxias, 5650, Bairro Buenos Aires, CEP 64008-780, Teresina, PI, Brazil.
Email: jorge.hashimoto@embrapa.br

Food Science and Technology International 0(0) 1–13

DOI: 10.1177/10820132221121172
journals.sagepub.com/home/fst
SAGE

population meets the daily recommendation of consumption of 75 g/day of whole grains, and it is necessary to increase this percentage in order to have a positive impact on public health.

A better nutritional complement will be obtained when there is a combination of grass and legume flour (Nair et al., 2013). Mung bean grains [*Vigna radiata* (L.) R. Wilczek] contain high levels of protein (14.6 to 33.0 g / 100 g), of bioactive compounds, minerals (5.9 to 7.6 mg / 100 g of Fe) and vitamins (Dahiya et al., 2015). It has good digestibility, detoxifying, calming, reducing the effects of heat stroke (Tang et al., 2014), regulating the flora of enterobacteria, reduces the risk of hypercholesterolemia, coronary heart disease and cancer prevention (Hou et al., 2019; Kruawan et al., 2012). This pulse is cultivated mainly in India and Myanmar, each country contributing about 30% of the world production of 5.3 mt, followed by China (16%), Thailand (6%), Indonesia (5%), Kenya (3%) and Tanzania (1%) (Nair et al., 2020).

Whole mung bean flour (WMF) is more nutritious than cotyledon mung bean flour (CMF), and contains more than twice as much dietary fiber, about 10.6% (Skylas et al., 2018). But CMF has been more used, comprising 50% (Fathonah et al., 2020b) in gluten-free cookies (GF), 60% (Fathonah et al., 2018, 2020a) and 100% (Adair et al., 2001; Sakung et al., 2021) of the farinaceous ingredient in biscuit formulations.

To elaborate GF biscuits formulations, brown rice flour (BRF) is an interesting option, as it also favours amino acid complementation. It contains more nutrients and bioactive compounds than polished rice flour (Saleh et al., 2019), providing a light tan colour, nutty flavour and elastic texture that are transferred to baked goods (Islam et al., 2011). The antioxidants contained in BRF help to prevent various degenerative diseases (Widodo and Sirajuddin, 2019).

The improvement in nutritional complementation or obtaining more nutritious GF biscuits must be associated with excellent physical and physicochemical characteristics. In this sense, a simplex-centroid mixture design was applied to evaluate the effect of different proportions of WWF, WMF and BRF.

MATERIALS AND METHODS

Raw material

Mung bean grains (line BAG-3) developed by the breeding program of Embrapa Mid-North were used. WWF, BRF and other ingredients for the formulation of the biscuits were purchased from the local grain market (Teresina, Brazil). The mung beans were ground in a KitchenAid (Kl418ARONA) attachment adjusted to obtain the smallest particle size, coupled to the Stander mixer (KitchenAid, K5SS, Whirlpool Corporation, Springfield, Ohio, USA) drive shaft, operating at the lowest speed (144 rpm).

The chemical composition (AOAC, 2010), water absorption and solubility indexes (Anderson et al., 1969) were determined in three replicates. The total carbohydrate content was determined by difference and the hydrolyzable starch content method ISI 27-1e (ISI, 1999) was subtracted to estimate the dietary fiber content. The total energy value was estimated using Atwater conversion factors.

Biscuits formulations and processing

A standard salty biscuit formulation (Manley, 2000) which contained 59.36% WWF was used. Only the WWF ingredient was replaced by WMF and / or BRF (Table 1). The biscuit dough of each formulation was obtained by the two-phase method according to Manley (2000). Vegetable shortening (13.61%), syrup (1.89%), sugar (7.76%) and lecithin (0.16%) were placed in the stainless steel bowl (K5ASBP) of the mixer (KitchenAid, K5SS, Whirlpool Corporation, Springfield, Ohio, USA) and mixed with K5AB accessory attached at 96 rpm for 6 min. Then, one of the 10 farinaceous compositions (Table 1) and the salt (3.26%) were mixed at 96 rpm for a further 2 min. Subsequently, the bicarbonate ammonium (1.92%), chemical leavening agent (0.78%) and water (48,22% for WWF biscuit, adjusted according water absorption indices of each farinaceous composition) were added and homogenized at 96 rpm for another 2 min. The biscuit dough was laminated to a thickness of 2 mm, then cut into a circular shape of 3.7 cm in diameter and baked in an electric oven (Titã, FGE 4, Titã Eletrocomerciais, Ind. e Com. Ltda., Araraquara, São Paulo, Brazil) at 175°C for 16 min, with activated air circulation system and rotating tray support. Then they were cooled to room temperature, hermetically bottled (BOPP-M 25 µm) and stored at room temperature and protected from light.

Rheological properties

The pasting profile was determined in three replicates according to the ICC 162 method (International Association for Cereal Science and Technology, 1996) using an RVA viscometer (Rapid Visco Analyzer, RVA 4500, Perten Instruments, Hägersten, Sweden). The analysis was performed according to the equipment's standard program 2, using a flour mixture according to mixture design (Table 1), 4 g of solids (corrected to 14% moisture) suspended in 25 mL of deionized water.

Physical analysis of biscuits

Biscuits were assessed according to methods 10.50.05 [diameter, thickness and spread factor (SF)] and 10.50.01 [specific volume (SV)] of AACC (2010). From the relationships between the dimensions of the biscuits and the respective dough cut in a cylindrical shape, the expansion indices were determined: radial (REI), thickness (TEI)

Table 1. Simplex-centroid design for ternary mixtures with 3 additional equidistant internal points and characteristics physical and physicochemical characteristics of wholemeal savory biscuits.

Whole flours proportions			Wholemeal biscuits characteristics											
WWF	WMF	BRF	REI	TEI	VEI	SF	SV (cm^{-3} g^{-1})	Hardness (N)	Fractu-rability (mm)	L*	a*	b*	ΔE	a_w
1	0	0	0.87 ± 0.03	5.33 ± 0.63	4.01 ± 0.31	3.06 ± 0.43	1.83 ± 0.17	40.89 ± 5.65	1.77 ± 0.43	57.67 ± 0.53	12.40 ± 0.42	29.22 ± 0.45	0.00 ± 0.00	0.52 ± 0.01
0	1	0	1.00 ± 0.03	2.79 ± 0.33	2.79 ± 0.33	6.75 ± 0.91	1.45 ± 0.18	14.04 ± 1.61	0.31 ± 0.16	53.02 ± 0.19	7.95 ± 0.47	28.67 ± 0.60	6.51 ± 0.57	0.44 ± 0.01
0	0	1	0.95 ± 0.02	2.13 ± 0.36	1.94 ± 0.38	8.53 ± 1.50	1.03 ± 0.20	1.27 ± 0.36	0.48 ± 0.43	73.12 ± 1.18	4.85 ± 1.53	25.59 ± 2.31	17.70 ± 1.56	0.44 ± 0.01
1/2	1/2	0	0.97 ± 0.02	2.95 ± 0.45	2.75 ± 0.42	6.20 ± 1.02	1.34 ± 0.21	23.72 ± 3.78	0.44 ± 0.07	56.78 ± 0.74	9.96 ± 1.25	30.80 ± 1.13	3.35 ± 1.07	0.46 ± 0.01
1/2	0	1/2	0.92 ± 0.02	3.55 ± 0.70	2.98 ± 0.57	4.93 ± 0.86	1.46 ± 0.28	18.05 ± 3.12	0.73 ± 0.13	61.97 ± 0.45	10.70 ± 0.79	29.83 ± 1.21	4.82 ± 0.57	0.45 ± 0.01
0	1/2	1/2	1.01 ± 0.03	2.75 ± 0.25	2.79 ± 0.30	6.82 ± 0.61	1.32 ± 0.17	16.13 ± 3.02	0.40 ± 0.07	61.861.63 ±	9.36 ± 2.72	31.40 ± 6.29	7.36 ± 4.45	0.46 ± 0.01
1/3	1/3	1/3	0.99 ± 0.03	2.69 ± 0.27	2.62 ± 0.35	6.85 ± 0.70	1.27 ± 0.16	15.89 ± 1.98	0.42 ± 0.12	58.73 ± 1.85	11.04 ± 1.42	32.182.45 ±	4.38 ± 2.03	0.45 ± 0.02
2/3	1/6	1/6	0.91 ± 0.02	3.72 ± 0.43	3.12 ± 0.48	4.60 ± 0.48	1.47 ± 0.22	31.18 ± 5.34	0.69 ± 0.08	59.51 ± 0.86	11.35 ± 0.65	27.80 ± 4.57	3.81 ± 3.69	0.45 ± 0.01
1/6	2/3	1/6	1.00 ± 0.02	2.93 ± 0.28	2.91 ± 0.33	6.34 ± 0.59	1.48 ± 0.17	17.09 ± 4.79	0.42 ± 0.09	56.74 ± 0.63	9.24 ± 1.06	29.59 ± 0.82	3.66 ± 0.67	0.45 ± 0.01
1/6	1/6	2/3	0.96 ± 0.02	2.44 ± 0.31	2.270.37 ±	7.38 ± 0.80	1.090.16 ±	6.43 ± 2.03	0.33 ± 0.10	64.95 ± 0.84	7.57 ± 0.90	29.84 ± 1.73	8.981.21 ±	0.44 ± 0.01
1/3	1/3	1/3	0.97 ± 0.02	2.86 ± 0.27	2.69 ± 0.31	6.31 ± 0.58	1.33 ± 0.14	15.49 ± 2.01	0.49 ± 0.08	59.57 ± 0.58	10.48 ± 0.44	30.90 ± 0.50	3.27 ± 0.92	0.44 ± 0.02
1/3	1/3	1/3	0.99 ± 0.03	3.19 ± 0.54	3.15 ± 0.66	5.92 ± 1.15	1.54 ± 0.32	20.45 ± 4.11	0.60 ± 0.16	57.51 ± 1.30	11.12 ± 1.32	31.57 ± 1.05	3.36 ± 1.15	0.47 ± 0.00

WWF: Whole wheat flour or x_1; WMF: Whole mung flour or x_2; BRF: Whole rice flour or x_3; REI: Radial expansion index; TEI: Thickness expansion index; SF: Spread factor; VEI: Volumetric expansion index; SV: Specific volume; L*: L colour value; a*: a colour value; b*: b colour value; ΔE: Colour difference; a_w: Water activity.

and volumetric (VEI). The hardness (N) and fracturability (mm) was determined in five replicates in the TAXT2i (Stable Micro Systems, London, England), with the HDP/3PB and HDP0/90 accessories, using the analytical parameters: pre-test speed = 1.0 mm s^{-1}; test speed = 3.0 mm s^{-1}; post-test speed = 10.0 mm s^{-1}; distance 5 mm and three point bending test probe. The water activity (a_w) was determined in three replicates on the Aqualab 4TEV (Decagon, Pullman, USA) at 25.0 ± 0.30°C, and the colour parameters (CIE L*a*b*) in four replicates on the portable colorimeter (MiniScan XE Plus, Modelo 45/0-L, Hunter Associates Laboratory Inc., Reston, VA, USA), 10° observer angle and D65 illuminant. The colour difference ($\Delta E = [(\Delta L)^2 + (\Delta a)^2 + \Delta b)^2]^{0.5}$) was calculated in relation to WWF biscuits.

Statistical analysis

The data were submitted to multiple regression and Pearsońs correlations analysis using the Statistica program (StatSoft, Version 10, OK, USA). The special or reduced cubic model was used to predict the response in the ternary diagram, expressed as the general equation (Equation 1):

$$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \beta_{123} x_1 x_2 x_3 \quad (1)$$

Where y represents the response variable and the estimated coefficients represented by: β1, β2 and β3 (linear), β12, β13 and β23 (binary interactions) and β123 (ternary interaction). The significant models were submitted to the analysis of global desirability (D), under equity, for 's' and 't' equal to 1.

Table 2. Chemical and physicochemical characteristics of the whole flours.

	Wheat	Mungbean	Rice
Moisture (%)	7.64 ± 0.78	13.68 ± 0.05	10.29 ± 0.18
Protein (%)	13.84 ± 0.38	25.65 ± 0.08	7.99 ± 0.10
Fat (%)	2.38 ± 0.03	1.58 ± 0.18	2.04 ± 0.04
Ash (%)	1.29 ± 0.03	2.96 ± 0.09	0.75 ± 0.49
Carbohydrates (%)	59.75 ± 1.49	31.88 ± 0.72	70.09 ± 1.60
Total dietary fiber (%)	15.10 ± 2.07	24.25 ± 0.86	8.85 ± 1.85
Energy (kcal g^{-1})	315.77 ± 6.12	244.36 ± 4.20	330.65 ± 6.35
Mean particle size (μm)	343.54	373.56	396.01
Aw	0.51 ± 0.00	0.52 ± 0.00	0.54 ± 0.00
Colour value L*	75.44 ± 0.71	82.02 ± 0.13	82.21 ± 0.05
Colour value a*	3.66 ± 0.26	0.76 ± 1.44	1.13 ± 0.05
Colour value a*	14.68 ± 0.42	13.73 ± 3.73	13.15 ± 0.18
WWF colour difference (ΔE)	0 ± 0.0	8.05 ± 0.45	7.40 ± 0.72
WAI (g g^{-1})	0.95 ± 0.04	1.51 ± 0.20	1.01 ± 0.09
WSI (%)	8.05 ± 0.33	25.20 ± 0.51	2.92 ± 0.31

Aw: water activity; WAI: water absorption index; WSI: water solubility index.

RESULTS AND DISCUSSION

The chemical composition, physical and physical-chemical characteristics of wholemeal flours were different (Table 2). WMF stands out for its high protein, dietary fiber and ash content, almost two and three times higher than WWF and BRF, respectively, and low caloric value. WWF color is more distinct compared to WMF and BRF, which are more similar. Due to the high protein and fiber content the WSI value of WMF was more than 3 and 8 times higher than WWF and BRF, respectively, requiring adjustment in the amount of water added during dough preparation (Table 2).

Rheological properties of mixtures

RVA provides multi-parameter values: peak viscosity (PV), trough (TR), breakdown (BD), final viscosity (FV), setback (SB) and pasting temperature (PT), and the behavior of food polymers and their interactions are related to viscosity (Sibian and Riar, 2020).

High values in the viscosity parameters (PV, TR, BD, FV, and SB) were obtained in mixtures that contained high levels of WMF (Table 3), which is a flour with low starch content, high levels of protein and dietary fiber (Table 2). Kim et al. (2007) and Zou et al. (2019) obtained similar values in the viscosity profile, which was attributed to the high amylose content of mung beans, which is larger than those of other legume and cereal starches. According to Eliasson (2004), the paste property is the most important functional property of starch, which is provided by amylose and amylopectin. However, it is amylose that has the ability to gel. This occur due to amylose forming extensive hydrogen bonding network with water. Soluble dietary fiber (SDF) content also contributes significantly to increased viscosity (LIU et al., 2019) and mung beans may contain 5.6% SDF (Sudhakaran and Bukkan, 2021).

The rheological behavior of the parameters PV, TR, FV and SB for the different proportions of wholemeal flours mixtures were similar (Table 3). The peak time (pt), related to the total time required for cooking of flour, was always longer in flours containing BRF, possibly because the particle diameter was larger (Table 2), which required a longer time of hydration to complete the cooking. But when combined with WMF this time increased, indicating that hydration or gelatinization is slower, this may be associated with isolated or combined factors: mean particle size; lipid content; the content of dietary fiber and proteins, which may cause competition for hydration water; lower starch content and starch granule size.

According to Collar (2003) and Sibian and Riar (2021), the viscosity profile mainly depends from the composition

Table 3. Simplex-centroid design for ternary mixtures with 3 additional equidistant internal points and pasting profile of whole flour mixtures.

Whole flours proportions									
WWF (x_1)	WMF (x_2)	BRF (x_3)	Peak Viscosity (cP)	Trough (cP)	Breakdown (cP)	Final viscosity (cP)	Setback (cP)	Peak time (min)	Pasting temperature (°C)
1	0	0	1333.00 ± 33.06	864.67 ± 33.83	468.33 ± 17.62	2128.33 ± 66.37	1263.67 ± 32.58	8.85 ± 0.04	87.50 ± 0.05
0	1	0	5572.00 ± 26.23	3822.67 ± 61.08	1749.33 ± 77.68	7949.67 ± 147.43	4127.00 ± 205.12	9.55 ± 0.04	86.17 ± 0.23
0	0	1	1050.67 ± 2.52	933.33 ± 12.01	117.33 ± 13.32	1819.00 ± 28.21	885.67 ± 16.50	9.38 ± 0.04	77.50 ± 0.05
1/2	1/2	0	3152.00 ± 39.59	2499.00 ± 24.27	653.00 ± 16.37	6451.67 ± 47.86	3952.67 ± 23.97	9.55 ± 0.04	88.35 ± 0.00
1/2	0	1/2	1056.67 ± 4.04	851.33 ± 10.69	205.33 ± 8.08	2197.00 ± 49.96	1345.67 ± 39.53	8.62 ± 0.04	79.78 ± 0.55
0	1/2	1/2	2399.67 ± 9.02	2272.00 ± 21.38	127.67 ± 20.60	6093.33 ± 33.20	3821.33 ± 13.58	10.91 ± 0.31	85.45 ± 0.40
1/3	1/3	1/3	1901.00 ± 45.03	1778.33 ± 45.94	122.67 ± 10.97	5033.00 ± 157.79	3254.67 ± 111.85	10.02 ± 0.14	86.28 ± 0.03
2/3	1/6	1/6	1648.00 ± 39.74	1218.67 ± 28.54	429.33 ± 12.42	3478.67 ± 46.06	2260.00 ± 19.97	9.02 ± 0.10	86.55 ± 0.52
1/6	2/3	1/6	4000.67 ± 31.02	3422.00 ± 19.97	578.67 ± 32.15	6866.67 ± 155.46	3444.67 ± 153.29	10.05 ± 0.04	87.82 ± 0.51
1/6	1/6	2/3	1394.00 ± 22.61	1366.00 ± 17.78	28.00 ± 5.00	3617.00 ± 24.25	2251.00 ± 8.00	11.89 ± 0.47	80.60 ± 0.48

WWF: Whole wheat flour or x_1; WMF: Whole mung flour or x_2; BRF: Whole rice flour or x_3.

and the structural integrity of molecules. This is more evident in food systems like bakery products, where protein, starch, and other ingredients like pentosans and lipids provide the consistency, and WMF has these differences in relation to two cereal flours (Table 2). The values of the linear regression coefficients for WMF were always much higher than those of the other two flours (Table 4), being the main responsible for the rheological characteristics. And when there were significant binary effects, WMF participated in the interaction, showing a synergistic effect for FV and antagonistic for BD (Table 4).

There were significant and high correlations ($r \geq 0.72$) between the viscosity parameters, with the exception of BD, which did not present a significant correlation with FV and SB (Table 5). These 5 viscosity parameters also did not show a significant correlation with the firmness and fracturability of the cookies, but TR, FV and SB showed a good positive correlation ($r \geq 0.76$) with REI (Table 5). The other physical characteristics (TEI, VEI, SF and SV) did not show significant correlations (Table 5). For Fustier et al. (2008), many aspects of the processing of biscuits and end products are related to the dough rheological behavior.

Physical properties of biscuits

Physical appearance is important for purchasing decision and the ingredients affect this characteristic (Klunklin and Savage, 2018). According to the analysis of variance the models obtained for SV were not significant, but significant for REI, TEI, VEI, SF, hardness and fracturability, explaining 93.27, 93.30, 79.40, 91.80, 90.98, and 89.21% of the variation, respectively (Table 6). These six characteristics were positively affected by the linear effects of WWF, WMF and BRF (Table 6).

According to the values of the regression coefficients, WMF influenced more the REI value, followed by BRF and WWF (Table 6). By the average REI values (Table 1), the diameter of the cookies retracted or kept the same value as the raw dough. Severe retraction was observed for the WWF biscuit, possibly there was a strengthening of the gluten network due to NaCl. When the proportion of WMF was higher, there was less retraction (Table 1). These results were opposite to those obtained by Zhao et al. (2019) and Silky and Tiwari (2014), and in agreement with Mancebo et al. (2016), possibly protein content associated with the presence of NaCl may have prevented the increase in REI value. Silva et al. (2021) when using a sweet biscuit formulation found an increase in REI, this may be associated with the high sucrose content, which makes the dough more fluid during baking, favoring the increase in the biscuit diameter.

The behavior of the TEI values (Figure 1(b)) was opposite to that of REI (Figure 1(a)), confirmed by $r = -0.80$ (Table 5). The presence of WWF favored the attainment of high TEI values, the effect of WMF was intermediate and that of BRF inferior (Figure 1(a)), and the interaction between WWF and WMF was antagonistic (Table 5). Similar results were obtained by Zucco et al. (2011); Zhao et al. (2019); Silky and Tiwari (2014) and Dhull et al. (2006) when replacing WF with pulse flours, however, Zucco et al. (2011) observed an increase in biscuit thickness with the use of finer leguminous flours (< 24 μm). The behavior of VEI (Figure 1(c)) values was similar to those of TEI (Figure 1(b)), confirmed by r = 0.95 (Table 5).

The SF values were affected only by linear effects, with greater intensity by BRF, intermediately by WMF and less intensely by WWF (Table 6), large proportions of BRF decreased the vertical height of the mass of the biscuit during baking, increasing the SF value (Figure 1(d)). There was no radial growth of the mass in the baking, and the REI values of biscuits of different formulations were very close, from 0.92 to 1.01 (Table 1). SF correlated positively with REI and negatively with TEI and VEI (Table 5). These results were opposite to those of Thongram et al. (2016) by replacing WF by 25% of cowpea flour, verifying increases in the diameter of the cookies without interference in height.

The hardness of the cookies was affected to a great extent by the WWF, and less so by the WMF. BRF did not affect the value (Table 6). Zucco et al. (2011) obtained similar results in the gradual WF replacement for coarse pulses flours up to 100%. However, Dhull et al. (2006) and Silky and Tiwari (2014) obtained harder biscuits when replaced for fine pulses flours to 30%. The acute effect of decreasing the biscuits hardness due to the replacement of wheat flour for rice flour was also reported in research carried out by Klunklin and Savage (2018) and Mancebo et al. (2016). According to these authors, the lower hardness is attributed to changes in the internal structure of the cookies. Thus, WWF may have contributed to the greater cohesion of this structure, or higher hardness, due to the gluten network. While, to Mancebo et al. (2016) and Sibian and Riar (2020), factors that reduce dough cohesiveness promote lower hardness, such as the high content of non-gluten forming proteins, lower water content and higher fat content.

WWF biscuits were more resistant to fracture (Table 1), suffering greater deformation before rupture, which may be associated with a higher value in the TEI. WMF biscuits were the most susceptible to fracturability (Table 1). Binary mixtures of WWF with WMF or BRF had antagonistic effects, which made the cookies more susceptible to fracture (Table 6).

Colour evaluation

Color and flavor are products of non-enzymatic browning reactions (Maillard) between reducing sugars and amino acids, but also due to dextrinization and caramelization (Zucco et al., 2011). According to the analysis of variance (Table 6), the regression models for the color parameters L*, a*, and ΔE were significant, explaining 96.54, 90.10, and 94.22% of the variation, respectively.

High proportions of BRF and / or WWF favored obtaining biscuits with a lighter surface, which corresponded to high L* values (Figure 2(a)), as the values of the linear coefficients of both higher than that of WMF (Table 6). When the proportion of WMF was increased in the formulation, there was a greater contribution to the darker coloration (Figure 2(a)). The presence of dark green pigmentation of the grain tegument resulted in low values for linear coefficients of WMF and its negative interaction with BRF (Table 6). The behavior for a* values (Figure 2(b)) were inverse to that L* value (Figure 2(a)), there was a smaller contribution from the linear effect of BRF and the interaction with WMF was synergistic (Table 6).

The only non-significant linear coefficient for ΔE was that of WWF, and its interactions with WMF (binary and

Table 4. Coefficients obtained by multiple regression analysis and data from analysis of variance of adjusted models for rheological parameters of whole flour mixtures.

	PV	TR	BD	FV	SB	pt	PT
(A)WWF	1299.49*	794.396^{ns}	505.10*	2067.76*	1273.37*	8.69*	87.64*
(B)WMF	5672.68*	3955.245*	1717.43*	7929.67*	3974.43*	9.40*	86.26*
(C)WRF	1041.95*	917.639^{ns}	124.31^{ns}	1856.86*	939.22^{ns}	9.83*	77.19*
AB	−1067.66^{ns}	745.948^{ns}	−1813.61*	5489.54*	4743.60^{ns}	0.79^{ns}	6.53^{ns}
AC	−625.12^{ns}	−362.597^{ns}	−262.52^{ns}	847.91^{ns}	1210.50^{ns}	−1.37^{ns}	−11.20*
BC	−3462.75^{ns}	−190.234^{ns}	−3272.52*	4871.73*	5061.96^{ns}	6.38^{ns}	14.03*
ABC	−598.94^{ns}	205.765^{ns}	−804.71^{ns}	−7884.35^{ns}	−8090.12^{ns}	13.37^{ns}	35.66^{ns}
r^2	0.9889	0.9719	0.9873	0.9978	0.9669	0.6460	0.9889^{ns}
r^2adj	0.9667	0.9157	0.9619	0.9935	0.9007	0.0000	0.9667^{ns}
F	51.60*	17.30*	38.91*	230.84*	14.60*	0.91^{ns}	44.51*
p	0.004*	0.020*	0.006*	0.000*	0.025*	0.58^{ns}	0.005*
CV (%)	10.69	16.39	22.05	3.90	14.40	10.48	0.83

*: Significative ($p < 0.05$); ^{ns}: Not significative; PV: Peak viscosity; TR: Trough; BD: Breakdown; FV: Final viscosity; SB: Seatback; pt: Peak time; PT: Pasting temperature.

Table 5. Correlation coefficients between physical and physicochemical characteristics of whole savory biscuits and rheological characteristics of whole flour mixtures.

	L	a	b	ΔE	Hard-ness	Frac-Tura-bility	REI	TEI	VEI	SF	SV	a_w	PV	TR	BD	FV	SB	PT	pt
L	1.00	−0.61	−0.49	0.83*	−0.57	−0.11	−0.12	−0.39	−0.61	0.49	−0.68*	−0.30	−0.69*	−0.63*	−0.68*	−0.67*	−0.66*	−0.85*	0.17
a		1.00	0.53	−0.92*	0.87*	0.58	−0.47	0.77*	0.84*	−0.86*	0.77*	0.64*	−0.12	−0.16	−0.03	−0.04	0.06	0.63	−0.37
b			1.00	−0.56	0.18	−0.12	0.32	0.02	0.19	−0.12	0.14	0.15	0.13	0.24	−0.14	0.43	0.57	0.47	0.37
ΔE				1.00	−0.84*	−0.48	0.30	−0.71*	−0.84*	0.81*	−0.82*	−0.61	−0.20	−0.16	−0.23	−0.24	−0.29	−0.78*	0.26
Hard-ness					1.00	0.77*	−0.63	0.92*	0.94*	−0.94*	0.89*	0.82*	−0.06	−0.15	0.15	−0.10	−0.04	0.67*	−0.51
Frac-Tura-bility						1.00	−0.85*	0.93*	0.82*	−0.82*	0.75*	0.91*	−0.40	−0.51	−0.09	−0.55	−0.55	0.19	−0.53
REI							1.00	−0.80	−0.59	0.75*	−0.50	−0.61	0.63	0.76*	0.23	0.79*	0.77*	0.12	0.58
TEI								1.00	0.95	−0.96*	0.90*	0.89*	−0.22	−0.34	0.07	−0.35	−0.34	0.40	−0.56
VEI									1.00	−0.95*	0.98*	0.86*	0.02	−0.08	0.22	−0.08	−0.07	0.60	−0.49
SF										1.00	−0.91*	−0.77*	0.17	0.28	−0.09	0.27	0.24	−0.45	0.57
SV											1.00	0.78*	0.18	0.07	0.37	0.03	−0.01	0.62	−0.56
a_w												1.00	−0.20	−0.26	−0.03	−0.24	−0.22	0.47	−0.28
PV													1.00	0.97*	0.87*	0.91*	0.80*	0.54	0.07
TR														1.00	0.72*	0.96*	0.87*	0.54	0.23
BD															1.00	0.63	0.50	0.44	−0.27
FV																1.00	0.97*	0.62	0.31
SB																	1.00	0.65*	0.37
PT																		1.00	−0.09
pt																			1.00

: Significative ($p < 0.05$); L: L colour value; a* : a colour value; b* : b colour value; ΔE: Colour difference; REI: Radial expansion index; TEI: Thickness expansion index; VEI: Volume expansion index; SV: Specific volume; SF: Spread factor; a_w : Water activity; PV: Peak viscosity; TR: Trough; BD: Breakdown; FV: Final viscosity; SB: Setback; PT: Pasting temperature; pt: Peak time.

Table 6. Coefficients obtained by multiple regression analysis and data from analysis of variance of adjusted models for rheological parameters of flour mixtures, dough texture profiles, physical and physicochemical savory biscuits characteristics.

	REI	TEI	VEI	SF	SV	Hardness	Fracturability	L*	a*	b*	ΔE	a_w
(A)WWF	0.87*	5.31*	4.00*	2.99*	1.82*	42.12*	1.72*	58.00*	12.42*	28.62*	0.55^{ns}	0.51*
(B)WMF	1.00*	2.85*	2.85*	6.65*	1.49*	14.05*	0.35*	53.03*	7.92*	28.47*	6.19*	0.44*
(C)WRF	0.95*	2.07*	1.88*	8.67*	0.99*	0.04^{ns}	0.46*	73.07*	4.58*	25.82*	17.68*	0.44*
AB	0.11^{ns}	−4.35*	-2.54^{ns}	4.85^{ns}	-1.15^{ns}	-12.50^{ns}	−2.39*	6.45^{ns}	-0.87^{ns}	5.82^{ns}	0.83^{ns}	-0.10^{ns}
AC	0.01^{ns}	-0.88^{ns}	-0.17^{ns}	-3.32^{ns}	0.02^{ns}	-12.08^{ns}	−1.73*	−13.13*	7.80^{ns}	8.96^{ns}	−15.04*	-0.13^{ns}
BC	0.11^{ns}	1.20^{ns}	1.67^{ns}	-3.21^{ns}	0.31^{ns}	31.46^{ns}	0.07^{ns}	-4.93^{ns}	11.25*	17.16^{ns}	−19.63*	0.09^{ns}
ABC	0.29^{ns}	-1.59^{ns}	0.01^{ns}	11.06^{ns}	0.72^{ns}	-59.74^{ns}	2.21^{ns}	-31.89^{ns}	7.30^{ns}	-5.45^{ns}	-13.48^{ns}	0.03^{ns}
r^2	0.9694	0.9695	0.9064	0.9627	0.8369	0.9590*	0.9509	0.9843	0.9550	0.7317	0.9737	0.8818
r^2adj	0.9327	0.9330	0.7940	0.9180	0.6411	0.9098*	0.8921	0.9654	0.9010	0.4098	0.9422	0.7400
F	26.39*	26.51*	8.07*	21.52*	4.27^{ns}	19.50*	16.15*	52.12*	17.68*	2.27^{ns}	30.90*	6.22*
p	0.0012*	0.0012*	0.0184*	0.0020*	0.0662^{ns}	0.0025*	0.0039*	0.0002*	0.0032*	0.1928^{ns}	0.0008*	0.0317*
Lack of fit	0.63^{ns}	0.73^{ns}	0.79^{ns}	0.68^{ns}	0.66^{ns}	0.43^{ns}	0.28^{ns}	0.62^{ns}	0.17^{ns}	0.12^{ns}	0.19^{ns}	0.75^{ns}
CV (%)	1.13	6.86	8.08	6.60	9.11	16.91	21.84	1.58	6.72	4.73	19.09	2.37

* : Significative ($p < 0.05$).); ^{ns} : Not significative; REI: Radial expansion index; TEI: Thickness expansion index; SF: Spread factor; VEI: Volumetric expansion index; SV: Specific volume; L*: L colour value; a* : a colour value; b* : b colour value; ΔE: Colour difference; a_w : Water activity.

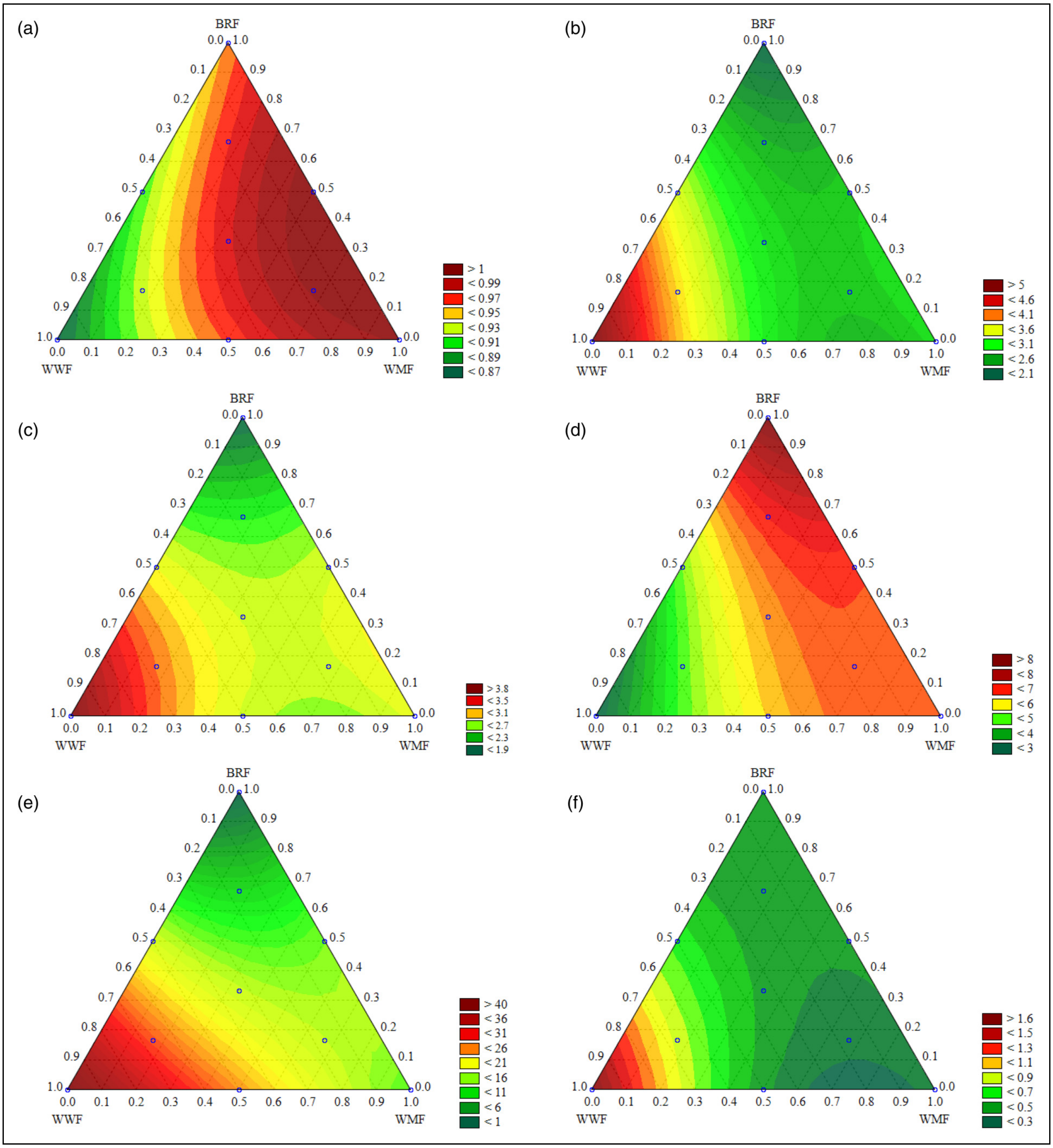

Figure 1. Effect of different proportions of whole wheat flour (WWF), brown rice flour (BRF) and whole mung flour (WMF) on radial (a), thickness (b) and volumetric (c) expansion index, spread factor (d), hardness (e) and fracturability (f) of savory biscuits.

ternary), the other binary interactions had negative effects (Table 6). The ΔE showed a high positive correlation (Table 5) with the L* value (r = 0.83) and negative with the a* value (r = −0.92).

The results were similar to those of Zhao et al. (2019). When increasing the proportion of yellow pea flour, the darkening was attributed to the Maillard reaction during cooking, in the case of WMF, there was also a contribution of the dark green color of the tegument (Figure 2(a)). Zhao et al. (2019) also observed increases in a* and b* values, and related to the reaction of reducing sugars with amino acids and pigment oxidation, respectively. Probably the WMF color masked the resulting color from these reactions, decreasing the a* values (Figure 2(b)). Zucco et al. (2011) found that the increased replacement of wheat flour by legume flour, even for those with white husk, darkened

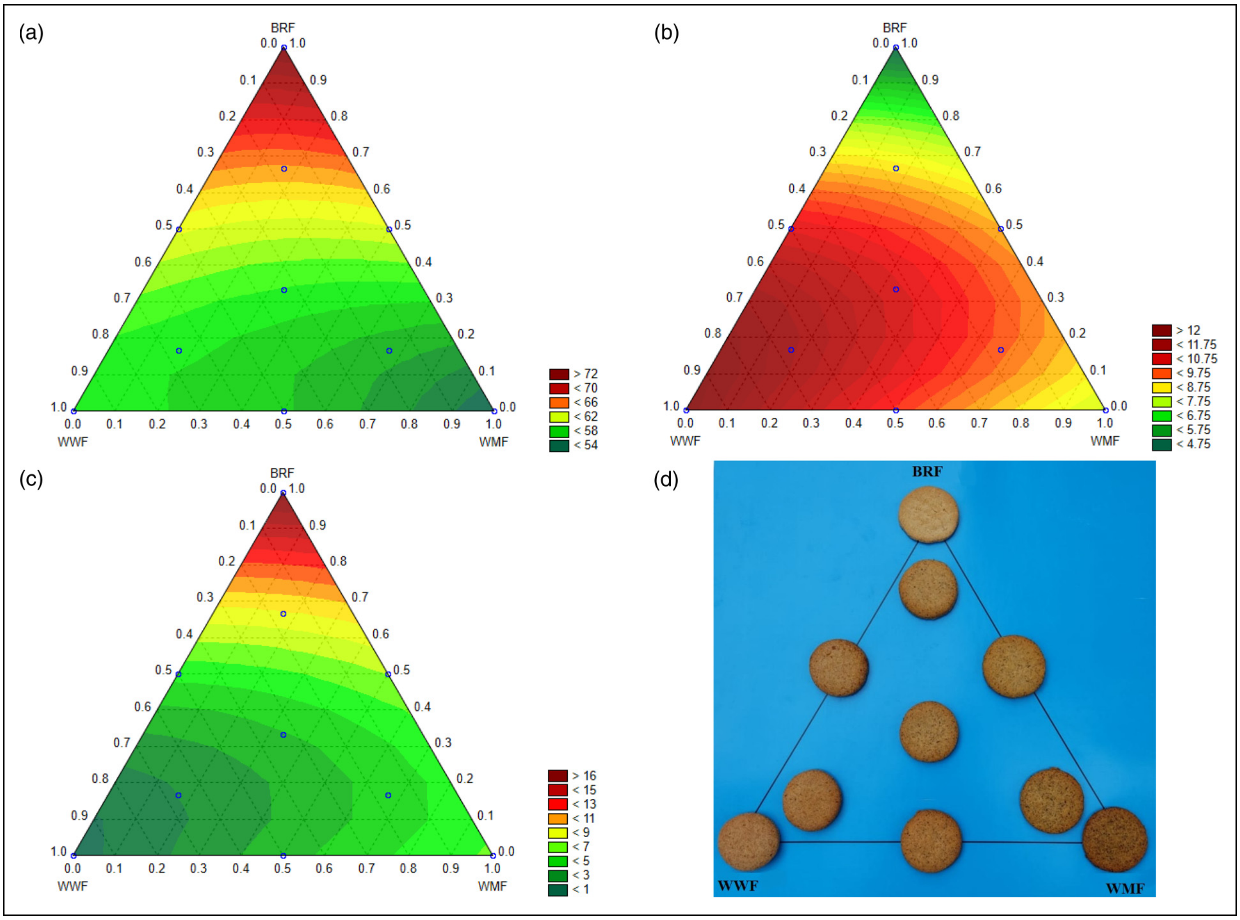

Figure 2. Effect of different proportions of whole wheat flour (WWF), brown rice flour (RBF) and whole mung flour (WMF) on L * (a), a * (b) color difference (c) and appearance (d) visual of savory biscuits.

the surface of the cookies, which was attributed to the high protein content and different amino acid compositions. Cady et al. (1987) attributed the reduction in the L * value to the increase in reducing sugars in legume flours.

Water activity

The a_w values ranged from 0.44 to 0.47 (Table 1). The model with $r^2 = 0.740$ is biased, presenting only significant linear coefficients. WWF favored the increase of a_w value in biscuits, while WMF and BRF contributed similarly to the reduction (Table 6).

Global desirability

In this analysis, 4 important physical characteristics of biscuits (Figure 3) were considered: higher REI values and lower TEI values, as mentioned by Zucco et al. (2011), doughs that spread further in the baking are desirable. And biscuits with texture characteristics similar to the WWF-based cream-cracker, with hardness close to 20 N (11.62 to 20.62 N) and fracturability close to 2 mm (1.34 to 2.55 mm), that in this range of values were sensorially acceptable, with grades from 6.68 to 7.44, according to Idowu et al. (2019). Under these conditions, the best formulation obtained meets up to 54% of the required conditions (Figure 3), consisting of 49% WWF, 24% WMF and 27% BRF.

CONCLUSIONS

Most of the physical characteristics of the savory biscuits were affected only by the linear effects of WWF, WMF and BRF, with the exception of the L* and a* value, ΔE, TEI and fracturability. Only REI showed a positive correlation with some rheological parameters of the mass. WMF did not change the radial dimension of the savory biscuits, but WWF and BRF caused retraction, and the dough increased in the vertical direction. WMF has contributed to reduce the high hardness and fracturability of WWF biscuits, indicating that it is an excellent option for improving physical quality. For the binary mixture of WMF and BRF

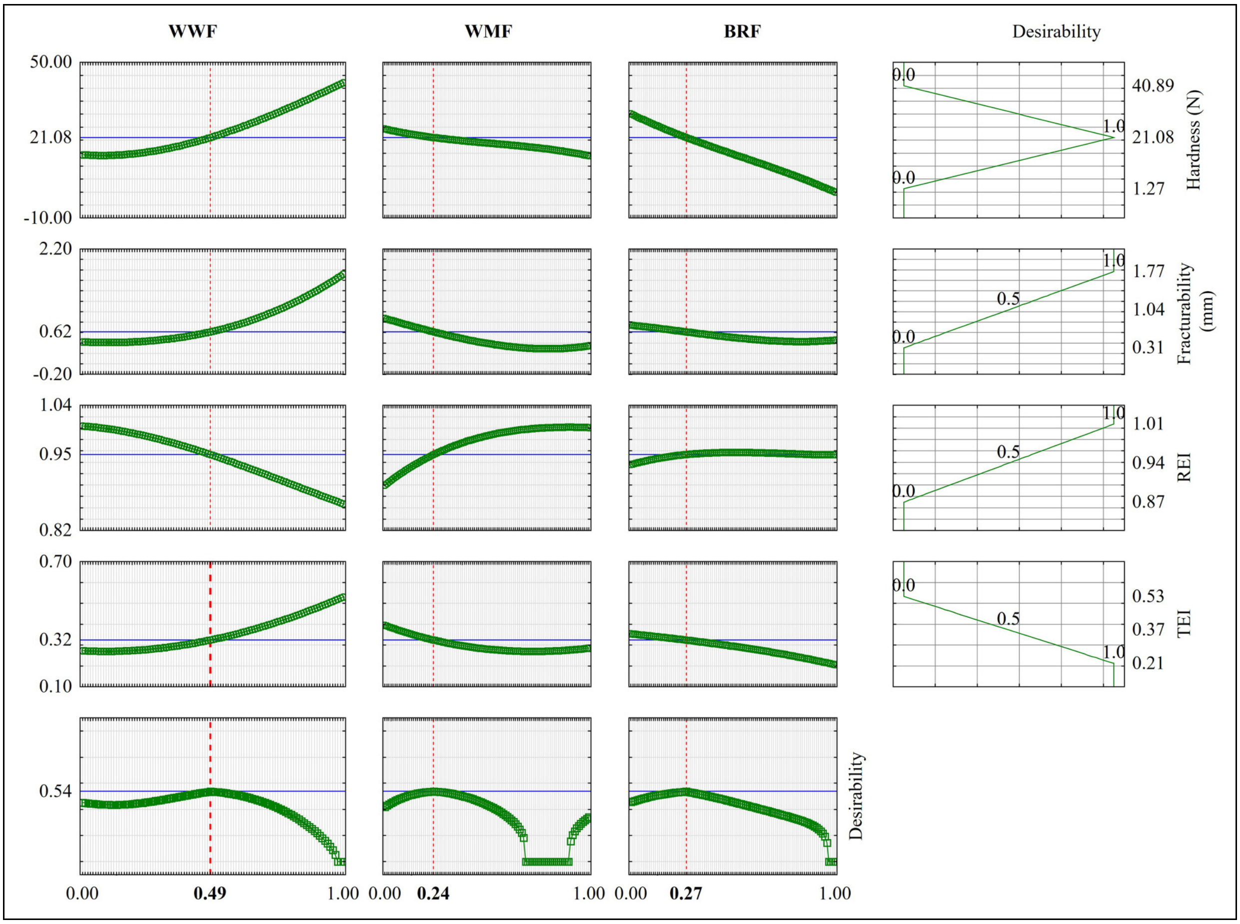

Figure 3. Profiles for predicted value and desirability for mixture of whole wheat (WWF), whole mung bean (WMF) and brown rice (BRF) flours considering medium hardness, high fracturability and radial expansion, and low thickness in savory biscuits.

there was also an improvement in all physical characteristics, indicating that WMF is an excellent choice of whole flour for the production of savory biscuits.

ACKNOWLEDGEMENETS

The authors would like to thank the Brazilian research funding agencies: Empresa Brasileira de Pesquisa Agropecuária (11.15.02.002.03.08.003 and 20.18.01.022.00.04), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), and Conselho Nacional de Desenvolvimento Científicos e Tecnológico (313750/2019-0). The Universidade Federal do Piauí (UFPI) provided part of the infrastructure for research.

DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

FUNDING

The author(s) received no financial support for the research, authorship, and/or publication of this article

ORCID iD

Jorge Minoru Hashimoto https://orcid.org/0000-0001-6474-7814

REFERENCES

AACC (2010) *Approved Methods of Analysis. Method 10-50.05*. 11th ed. St Paul: American Association of Cereal Chemists, 2010.

Adair M, Knight S and Gates G (2001) Acceptability of peanut butter cookies prepared using mungbean paste as a fat ingredient substitute. *Journal of the American Dietetic Association* 101(4): 467–469.

Anderson RA, Conway HF, Pfeifer VF, et al. (1969) Gelatinization of corn grits by roll-and extrusion-cooking. *Cereal Science Today* 14(1): 4–11.

AOAC (2010) *Official Methods of Analysis of Association of Official Analytical Chemists.* 18th Edition, Washington, DC.

Cady ND, Carter AE, Kayne BE, et al. (1987) Navy bean flour substitution in a master mix used for muffins and cookies. *Cereal Chemistry* 64(3): 193–195.

Collar C (2003) Significance of viscosity profile of pasted and gelled formulated wheat doughs on bread staling. *European Food Research and Technology* 216(6): 505–513.

Dahiya PK, Linnemann AR, Van Boekel MAJS, et al. (2015) Mung bean: Technological and nutritional potential. *Critical Reviews in Food Science and Nutrition* 55(5): 670–688.

Dhull N, Singh N, Panghal A, et al. (2006) Study of the effect of pulse flours on quality of biscuits. *Annals of Biology* 22(1): 75–78.

Doblado-Maldonado AF, Pike OA, Swley JC, et al. (2012) Key issues and challenges in whole wheat flour milling and storage. *Journal of Cereal Science* 56(2): 119–126.

Eliasson AC (2004) *Starch in Food: Structure, Function, and Applications*. Cambridge: Woodhead Publishing Limited, 590 p.

Fathonah S, Rachmawati R, Rosidah R, et al. (2020a) An innovation of high-energy and protein biscuits made of black rice flour substituted with mung bean flour. *International Journal of Research Innovation and Entrepreneurship* 1(2): 69–77.

Fathonah S, Rosidah R, Amalia B, et al. (2020b) The formulation of alternative gluten-free mung bean biscuits. Journal of Physics: Conference Series 1444: 012004. IOP Publishing.

Fathonah S, Rosidah R and Karsinah K (2018) Teknologi penepungan kacang hijau dan terapannya pada biscuit. *Jurnal Kompetensi Teknik* 10(1): 12–21.

Fustier P, Castaigne F, Turgeon S, et al. (2008) Flour constituent interactions and their influence on dough rheology and quality of semi-sweet biscuits: A mixture design approach with reconstituted blends of gluten, water-solubles and starch fractions. *Journal of Cereal Science* 48(1): 144–158.

Hou D, Yousaf L, Xue Y, et al. (2019) Mung bean (*Vigna radiata* L.): Bioactive polyphenols, polysaccharides, peptides, and health benefits. *Nutrients* 11(6): 1–28.

Idowu AT, Benjakul S, Sinthusamran S, et al. (2019) Whole wheat cracker fortified with biocalcium and protein hydrolysate powders from salmon frame: Characteristics and nutritional value. *Food Quality and Safety* 3(3): 191–199.

International Association for Cereal Science and Technology (1996) *Rapid Pasting Method Using the Newport Rapid Visco Analyser* (Vol. 162). Vienna: ICC Standard Method, pp. 123–456.

Inyang UE, Daniel EA and Bello FA (2018) Production and quality evaluation of functional biscuits from whole wheat flour supplemented with acha (fonio) and kidney bean flours. *Asian Journal of Agriculture and Food Sciences* 6(6): 193–201.

ISI (1999) (International Starch Institute) Determination of reducing power and DE by Lane and Eynońs method. Avaiable at: www.starch.dk/isi/methods/27DE.htm (accessed 10 December 2021).

Islam MZ, Shams-Ud-Din M and Haque MA (2011) Studies on the effect of brown rice and maize flour on the quality of bread. *Journal of the Bangladesh Agricultural University* 9(2): 297–304.

Kim S-H, Lee B-H and Baik M-Y (2007) Chemical structure and physical properties of mung bean starches isolated from 5 domestic cultivar. *Journal of Food Science* 72(9): C471–477.

Klunklin W and Savage G (2018) Biscuits: A substitution of wheat flour with purple rice flour. *Advances in Food Science and Engineering* 2(3): 81–97

Kruawan K, Tongyonk L and Kangsadalampai K (2012) Antimutagenic and co-mutagenic activities of some legume seeds and their seed coats. *Journal of Medicinal Plants Research* 6(2): 3845–3851.

Kumar P, Yadava RK, Gollen B, et al. (2011) Nutritional contents and medicinal properties of wheat: A review. *Life Science and Medicine Research* 2011: 1–10.

Kumari N, Sindhu SC, Kumari V, et al. (2020) Nutritional evaluation of developed value added biscuits incorporating germinated pumpkin seed flour. *Journal of Phamacognosy and Phytochemistry* 9(5): 2808–2806.

Kyro C, Skeie G, Dragsted LO, et al. (2012) Intake of whole grain in scandinavia: Intake, sources and compliance with new national recommendations. *Scandinavian Journal of Public Health* 40: 76–84.

Liu X, Liu S, Xi H, et al. (2019) Effects of soluble dietary fiber on the crystallinity, pasting, rheological, and morphological properties of corn resistant starch. *LWT – Food Science and Technology* 111: 632-639.

Mancebo CM, Rodriguez P and Gómez M (2016) Assessing rice flour-starch-protein mixtures to produce gluten free sugar-snap cookies. *LWT-Food Science and Technology* 67: 127–132.

Manley D (2000) *Technology of Biscuit, Crackers and Cookie*. 3th ed. Cambridge, England: Woodhead Publishing Limited, pp. 0–191.

Nair RM, Schafleitner R and Lee S-H (2020) *The Mungbean Genome*. Pusa, New Delhi, India: Compendium of Plant Genomes, pp. 1–191.

Nair RM, Yang RY, Easdown WJ, et al. (2013) Biofortification of mungbean (*Vigna radiata*) as a whole food to enhance human health. *Journal of the Science of Food and Agriculture* 93(8): 1805–1813..

Protonotariou S, Batzaki C, Yanniotis S, et al. (2016) Effect of jet milled whole flour in biscuits properties. *LWT – Food Science and Technology* 74: 106–113.

Ragaee S, Guzar I, Abdel-Aal ESM, et al. (2012) Bioactive components and antioxidants capacity of ontario hard and soft wheat varieties. *Canadian Journal of Plant Science* 92(1): 19–30.

Sakung JM, Nuryanti S, Afadil A, et al. (2021) Evaluation of proximate and mineral composition of biscuit formulated using chayote (*Sechium edule*) and mung bean (*Vigna radiata*) flours. *Open Access Macedonian Journal of Medical Sciences* 9(A): 373–377.

Saleh ASM, Wang P, Wang N, et al. (2019) Brown rice versus white rice: Nutritional quality, potential health benefits, development of food products, and preservation technologies. *Comprehensive Reviews in Food Science and Food Safety* 18(4): 1070–1096.

Seal CJ and Brownlee IA (2010) Whole grains and health, evidence from observational and intervention studies. *Cereal Chemistry* 87(2): 167–174.

Sibian MS and Riar CS (2020) Formulation and characterization of cookies prepared from the composite flour of germinated kidney bean, chickpea, and wheat. *Legume Science* 2: e42.

Sibian MS and Riar CS (2021) Optimization and evaluation of composite flour cookies prepared from germinated triticale, kidney bean, and chickpea. *Journal of Food Processing and Preservation* 45: e14996.

Silky MPG and Tiwari A (2014) Development of high protein biscuits using pigeon pea brokens flours. *International Journal of Engineering and Innovative Technology* 4(6): 84–89.

Silva DJS, Hashimoto JM, Nabeshima EH, et al. (2021) Correlation between the rheological and technological properties of biscuits with different levels of replacement of wheat flour by rice and azuki bean flour. *International Journal of Food Science and Technology* 56(10): 5190–5200.

Skylas DJ, Molloy MP, Willows RD, et al. (2018) Effect of processing on mungbean (*Vigna radiata*) flour nutritional properties and protein composition. *Journal of Agricultural Science* 10(11): 16–28.

Sudhakaran MNS and Bukkan DS (2021) A review on nutritional composition, antinutritional components and health benefits of green gram (*Vigna radiata* (L.) Wilczek). *Journal of Food Biochemistry* 45(6): 1-19.

Tang D, Dong Y, Ren H, et al. (2014) A review of phytochemistry, metabolite changes, and medicinal uses of the common food mung bean and its sprouts (*Vigna radiata*). *Chemistry Central Journal* 8(4): 1–9.

Thongram S, Tanwar B, Chauhan A, et al. (2016) Physicochemical and organoleptic properties of cookies with legume flours. *Congent Food & Agriculture* 2(1): 1172389.

USDA (2000) Report of the Dietary Guidelines Advisory Committee on the Dietary Guidelines for Americans, 2000. Available at: www.dietaryguidelines.gov/sites/default/files/2019-05/FullDGACReport.pdf (accessed 15 November 2021).

Widodo S and Sirajuddin S (2019) Biscuit formulation with substitution of brown rice flour. *Journal of Business on Hospitality and Tourism* 5(2): 159–168.

Zhao J, Liu X, Bai X, et al. (2019) Production of biscuits by substitution with different ratios of yellow pea flour. *Grain & Oil Science and Technology* 2(4): 91–96.

Zucco F, Borsuk Y and Arntfield SD (2011) Physical and nutritional evaluation of wheat cookies supplemented with pulse flours of different particle sizes. *Food Science and Technology* 44(10): 2070–2076.