ORIGINAL ARTICLE

Nutritional, physical and sensory characteristics of bread with the inclusion of germinated basul (*Erythrina edulis*) flour

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Abstract The goal was to assess the effect of different substitution levels (SL) of wheat flour with germinated basul flour (GBF) on nutritional, physical, and sensory characteristics of bread. The previously soaked basul fruits were germinated, dried, and transformed into flour. This product substituted wheat flour in the following SL: 0 (control), 5, 10, 15, and 20% of GBF, respectively, for the processing of loaves of bread. Nutritional values were determined by AOAC method. The physical characteristics assessed were weight, volume, porosity, and colour. The Flash Profile technique was used for the sensory assessment. A significant increase in the content of protein and crude fibre (3.86 and 50.49%, respectively) and a decrease in the content of carbohydrates (2.57%) were observed in all loaves with SL of 20%. With this same SL, it was observed that the physical characteristics did not differ significantly, except for height. In the sensory characteristics, loaves made with 20% SL also had a sweet flavour and a spongy appearance, except for the colour (change to opaque colour), which gradually decreased with the increased SL. The inclusion of GBF in bread improved nutritional and sensory quality, without affecting physical quality, which is why it can be considered healthy food.

Keyword Basul flour · Germinated · Nutritional quality · Flash profile

Abbreviations

SL	Substitution level
GBF	Germinated basul flour
AOAC	Association of Official Analytical Chemists
NaClO	Sodium hypochlorite
GPA	Generalised Procrustes Analysis
WF	wheat flour

Introduction

Today, bread remains one of the basic diets in various regions of the world, such as South America, North America, the Middle East, and Europe (Yamsaengsung et al. 2010). One of the main ingredients used in the production of this product is refined wheat flour (without the bran layer), which contains one of the most important proteins called gluten, a component that plays a fundamental role in the techno-functional properties of bakery products. However, the high content of starch, and the low content of protein and dietary fibre (cellulose, arabinoxylan, β-glucan, fructans, and others) is not favourable from a nutritional and health point of view (Lappi et al. 2013; Sciarini et al. 2016; Vilcanqui et al. 2018). Products made with highly refined grains have been directly associated with weight gain. On the other hand, the whole-grain consumption includes the greater nutrient density of whole grains relative to refined grains and associations between higher whole-grain consumption and reduced risk of cardiovascular disease, type 2 diabetes, and obesity (Philip Karl and McKeown 2014). In order to contribute to the prevention of these diseases, researchers in food nutrition, science, and technology have designed strategies such as the inclusion of different legumes, which are mainly appreciated for their high content of protein, dietary fibre,

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digestible starch, and slow assimilation (Alonso et al. 2010).

Specifically, regarding the bakery industry, several studies have indicated the feasibility of partially replacing wheat flour with flour obtained from different legumes. Therefore, there has been an increase in nutritional quality, such as protein content, dietary fibre, phenolic compounds, and antioxidants, as well as a decrease in digestible starch (Angioloni and Collar 2012). For example, the addition of up to 20% of *Vigna unguiculata* (legume) flour has exhibited a successful performance in the different stages of the bread-making process, with sensory and physical characteristics similar to those of control samples. However, values greater than 20% have had negative effects, such as sticky dough difficult to handle and reduction in bread volume (McWatters et al. 2004). Despite these studies, the behaviour that bakery products would have in the physical and sensory characteristics have still not been clearly determined, given that, in some cases, loaves of bread have been obtained with dense and dry structure, low volume, and high hardness of the crumb. As a result, the production of loaves of bread with better nutritional components that can effectively contribute to health, without affecting technological and sensory quality, is still a challenge.

Up to 150 species of legumes are used in human and animal food (Alonso et al. 2010), of which many grow in the wild, such as *Erythrina edulis*, a plant native to Latin American. It is a legume tree with an average height of ten to fifteen metres, with intense dark green leaves and small spines in the midrib of the posterior aspect. These trees produce elongated pods that contain the fruits, which are given different denominations, such as 'basul', 'pajuro', 'poroto', 'water plant', or 'chachafruto', depending on the region where it is produced. The basul is a legume with a wide range of uses; however, fruits are used for human consumption. They are appreciated for their high protein content (18–25%) and high digestibility, surpassing other legumes and being similar to eggs with respect to those nutritional characteristics (Intiquilla et al. 2019). However, the information available regarding the functional, nutritional, and antioxidant properties of basul is still scarce, including its use in bakery products.

One of the factors that reduce the nutritional quality of legumes in general is the presence of some anti-nutrients, such as alkaloids, trypsin inhibitors, and phytates, i.e., components that hinder the use and assimilation of nutrients such as proteins and minerals (Handa et al. 2017). However, in order to improve nutritional quality and reduce anti-nutritional factors, various strategies, such as soaking and germination, have been used (Singh et al. 2015). This way, the goal of the present study was to determine the nutritional values, the physical characteristics, and the sensory quality in loaves of bread made with different inclusion levels of germinated basul flour (GBF).

Materials and methods

Collection of germinated basul fruits and supplies

The basul (fruits), in its stage of physiological maturity, was harvested in the community of Cruzpata, Lambrama district, Apurímac region, Peru, following the recommendations of the National Forest and Wild Fauna Service (SERFOR) in the use of wild flora (Authorisation No. 120-2019-MINA-GRI-SERFOR/ATFFS-APURÍMAC). The fruits were transported to the laboratories of the Micaela Bastidas of Apurímac National University (UNAMBA), conducting a selection and classification to eliminate the damaged fruits followed by a wash and disinfection (25 ppm NaClO for 10 min) to eliminate the presence of microorganisms and ensure safety in the next stage. The procedure described by Handa et al. (2017), with some modifications, was used for the germination process. The basul fruits were soaked with distilled water for 18 h and germinated for 96 h in the presence of light. In the next stage, the fruits were dried in a forced-air convection oven Memmert UF 55 at 60 °C for 15 h. The flour was obtained by grinding to a particle size of ≥ 250 μm (Yamsaengsung et al. 2010).

Formulation and preparation of loaves of bread with different substitution levels

Loaves of bread were formulated with five SL (0, 5, 10, 15 and 20%), replacing wheat flour with GBF (Table 1),

Table 1 Bread formulations with different substitution levels

Components	Substitution level				
	0 (Control)	5%	10%	15%	20%
WF (g)	500	475	450	425	400
GBF (g)	0	25	50	75	100
Sugar (g)	80	80	80	80	80
Butter (animal origin) (g)	70	70	70	70	70
Yeast (g)	15	15	15	15	15
Salt (g)	8	8	8	8	8
Water (g)	300	300	300	300	300
Total (g)	973	973	973	973	973

WF: wheat flour; GBF: germinated basul flour

SL0 (control): 100% WF + 0% GBF; SL5: 95% WF + 5% GBF; SL10: 90% WF + 10% GBF; SL15: 85% WF + 15% GBF; SL20: 80% WF + 20% GBF

according to the procedure described by Paucar et al. (2016), with slight modifications. The solid ingredients were mixed and kneaded with the addition of water using two speeds (NOVA10K kneader). Subsequently, the prepared dough was placed in stainless steel moulds, fermented at 40 °C for 40 min, and baked at 150 °C for 40 min. The loaves of bread were cooled at room temperature (20 °C) and then removed from the moulds, sliced, and packed in high-density polyethylene containers.

Determination of nutritional components

The proximate analysis of the samples was performed according to the methods described by the Association of Official Analytical Chemists, at the Food Nutritional Assessment Laboratory (LENA), Agraria la Molina National University (UNALM), Peru. Protein, fat, ash, moisture, and crude fibre contents were determined using the AOAC (2008) methods: 984.13; 2003.05; 942.05; 950.46; and 962.09, respectively, and the nitrogen-free extract by the difference of 100%.

Physical characteristics of bread

Volume and weight

The volumes of the loaves of bread (mL) were determined using laser topography (BVM-6610, Perten Instruments, Sweden), and the weight (g) using an analytical balance. The specific volumes (mL/g) were calculated dividing the volume by the weight of the loaves of bread (Vidaurre et al. 2019).

Porosity

Slices of the loaves type bread were photographed in colour using a photographic camera. The images were scanned (Canon MG3610, Japan) at 600 dpi resolution, and then converted to gray and processed using the ImageJ 1.51j8 Software (National Institutes of Health, USA). Using dimensions of known lengths, the pixel values were converted to units of length, and the images were binarised (black for gas cells and white for crumb); determining the number of gas cells per cm^2 and the average area of the gas cells per cm^2 (Vidaurre et al. 2019).

Instrumental colour

The colours of the bread crusts were measured using a portable colorimeter (3NH, NH310, Shenzhen, China). The L* (0 = black; 100 = white), a* (+ value = red; − value = green), and b* (+ value = yellow; − value = blue) values were recorded. Three surface points (three points from left to right by three points from top to bottom) were measured in each loaf of bread (Yamsaengsung et al. 2010)

Sensory characteristics of bread using the Flash Profile technique

The Flash Profile technique was applied with 18 evaluators (consumers ages between 17 and 50 years). In the first session, the samples were presented simultaneously and randomly. The evaluators were asked to list the sensory characteristics that best described the differences between the samples, i.e., they created their provisional list of attributes, and were instructed to avoid hedonic terms. This session lasted 30 min and was performed at room temperature (20–22 °C). In the second session, an interview was conducted to reach a consensus and avoid that two terms in each list described the same thing. This way, the evaluators managed to create their final lists of attributes. These lists were compared to ensure that the evaluators had not forgotten any important sensory dimension. This session lasted about 20 min (Dairou and Sieffermann 2002; Silva et al. 2016). Finally, in the third session, the samples were again presented simultaneously and randomly, and each evaluator carried out the sensory evaluation considering the attributes chosen. Draws were allowed and they were asked to classify the bread in increasing order of intensities on an ordinal scale. Each session lasted 20–30 min per evaluator (Dairou and Sieffermann 2002). Once the information was obtained, it was analysed using generalised Procrustes analysis (GPA) (Dijksterhuis and Gower 1991) to obtain the sensory map based on the consensus (Terhaag and Benassi 2010).

Statistical analysis

The data of the nutritional components and the physical characteristics of the loaves of bread were expressed as mean ± standard deviation, and analysed using the InfoStad free version 2011 software. The differences between the treatments were established by the analysis of variance (ANOVA) of a pathway followed by a multiple comparison of means obtained by the Tukey test, at a significance level of $p < 0.05$ for both cases. Sensory characteristics data obtained by Flash Profile were assessed using GPA, with the XLSTAT 2014 trial version software (Addinsoft, New York, USA).

Results and discussion

Nutritional components of bread made with the inclusion of germinated basul flour

Table 2 illustrates the results of the nutritional components of bread made with different SL replacing wheat flour with GBF. The results indicated that, as the SL increased, protein content increased significantly from 13.98% (SL0) to 14.52% (SL20). Contrary effects were observed regarding carbohydrate contents, whose values decreased significantly from 72.98% to 70.23% (for SL0 and SL20, respectively). Another important finding was an increase in crude fibre content, although the variations of this component were not significant.

In general, legumes have two times more protein content than cereals. This way, one of the intrinsic characteristics of these flours is the high contents of protein and dietary fibre (Angioloni and Collar 2012). Regarding protein content, the findings of the present study are in line with those of different studies that have assessed the production of bread with the inclusion of various legumes. For example, bread made with 100% sorghum flour obtained a protein content of 8.57%. However, when 10% was substituted with cowpea flour (*Vigna unguiculata*) protein content increased to 9.61%. The same result was observed when 10% was substituted with chickpea flour (*Cicer arietinum*), with an increase of up to 14.25% of protein content (Olojede et al. 2020).

The results of the present study indicated similar values with a substitution of 10% of wheat flour with GBF (14.29%), and higher values with 20% of GBF (14.52%). On the other hand, Wandersleben et al. (2018) assessed bread made with 2% of flaxseed flour, 10% of lupine flour, and 88% of wheat flour, obtaining a value of 17.08% in protein content, compared to 10.95% protein obtained with 100% of wheat flour; in other words, a higher value than that found in bread with the inclusion of GBF; results that

were attributed to the high content of this component in lupine flour, with 60.60% (Wandersleben et al. 2018).

The consumption of food from different legume sources is very important from a nutritional point of view and, therefore, for health, because high protein content of vegetable origin has advantages over sources of animal origin, given that the latter contain saturated fatty acids and cholesterol (Alonso et al. 2010). On the other hand, legumes contain high amounts of lysine, leucine, aspartic acid, glutamic acid, and arginine (Miñarro et al. 2012). This amino acid profile provides a balance when combined with cereals, in the present case wheat flour that are deficient with respect to these amino acids.

Additionally, in bread made with GBF, the free amino acid profile may have improved, according to the fundamentals of Hung et al. (2012), who pointed out that, during the germination process of a type of wheat, the amounts of free amino acids, such as the essential ones (isoleucine, leucine, phenylalanine and valine), had increased significantly, depending on weather conditions and other germination factors. So it would be convenient, in the future, to determine the amino acid profile in bread made with germinated legumes.

Another important factors indicated by the results of the present study were the progressive increase in crude fibre content, from 0.93% (SL0) to 1.46% (SL20), and contrary effects with respect to carbohydrate content, from 72.08% (SL0) to 70.23% (SL20). These results coincide with others obtained by other studies assessing bread made with 100% whole wheat flour, and 10% and 20% inclusion of soy flour, whose results regarding crude fibre content had been 4.62, 6.12, and 7.19%, respectively, i.e., there was an increase in fibre content as the SL using a legume source increased. For carbohydrate content, in the same formulations, there had been a reduction from 75.90 to 64.97%, respectively (Ndife et al. 2011). This same pattern of behaviour was observed by Olojede et al. (2020) and Wandersleben et al. (2018) in bread made with the

Table 2 Proximal composition of bread with different substitution levels

Components	Substitution level				
	0 (Control)	5%	10%	15%	20%
Protein (%)	13.98 ± 0.10[a]	14.28 ± 0.12[ab]	14.29 ± 0.08[ab]	14.37 ± 0.33[ab]	14.52 ± 0.23[b]
Fat (%)	12.00 ± 0.40[bc]	12.52 ± 0.15[c]	11.83 ± 0.09[b]	11.24 ± 0.21[a]	12.27 ± 0.09[bc]
Carbohydrate (%)	72.08 ± 0.07[c]	70.99 ± 0.46[ab]	71.30 ± 0.37[bc]	71.32 ± 0.23[bc]	70.23 ± 0.38[a]
Crude fibre (%)	0.93 ± 0.33[a]	0.94 ± 0.33[a]	1.13 ± 0.15[ab]	1.73 ± 0.12[b]	1.46 ± 0.39[ab]
Ash (%)	1.01 ± 0.20[a]	1.27 ± 0.20[a]	1.44 ± 0.21[a]	1.35 ± 0.08[a]	1.52 ± 0.27[a]

Average ± standard deviation (n = 3). Superscript with different letters in rows represent significant differences ($p < 0.05$). SL0 (control): 100% WF (wheat flour) + 0% GBF (germinated basul flour); SL5: 95% WF + 5% GBF; SL10: 90% WF + 10% GBF; SL15: 85% WF + 15% GBF; SL20: 80% WF + 20% GBF

[a] and [b] in rows represent significant differences

inclusion of lupine and bean flours. Therefore, it can be affirmed that the inclusion of different legumes increases the content of crude or dietary fibre, with opposite effects regarding carbohydrate content.

Despite the decrease in carbohydrate content in bread formulated with the inclusion of GBF, the presence of this component in food with legumes is very important from the point of view of nutrition and health. According to Alonso et al. (2010), legumes are considered excellent sources of slow-digesting starch, beneficial for health by slightly increasing postprandial glycemia, in comparison to fast-digesting starch (refined wheat).

The increase in fibre content in bread made with the inclusion of GBF is another aspect of interest for human consumption. The physicochemical properties of soluble fibre, such as galactomannans present in legumes (Miñarro et al. 2012), produce favourable physiological effects through the formation of viscous gels in the intestine, and mainly affect the decrease in glucose and fat absorption. On the other hand, insoluble fibres, such as cellulose, hemicellulose, and lignin, increase faecal volume and speed up intestinal transit time. Therefore, bread made with the inclusion of GBF could also be an alternative in the diet for the control of type 2 diabetes mellitus, overweight, and obesity and, on the other hand, in the prevention of constipation due to dietary fibre content.

Physical characteristics of bread made with the inclusion of germinated basul flour

Table 3 illustrates the results of the physical characteristics of bread made with different SL using GBF. In these results there were no significant differences in weight with the different inclusions of basul flour in comparison to the control (SL0: 326.03 g) except for the SL5 formulation (5% inclusion of GBF: 307.27 g). However, there was a significant reduction from 11.58 cm (SL0) to 7.19 cm (SL20) in the height of the loaves, i.e., as the amount of GBF increased, the height of the loaves decreased. Regarding the specific volume of the loaves, it was not significant differences between the treatments and the control ($p > 0.05$), as well as with respect to the number of gas cells and the area occupied by them (Fig. 1). Water content of the loaves after baking varied from 27.06% (SL0) to 28.11% (SL20), i.e., values that do not differ significantly. Other results such as the loss of weight of the loaves during baking ranged from 12.29% (SL0) to 14.60%. This result do not differ significantly except for SL20, which was significant.

In other studies, for example, bread formulated with 10% of chickpea flour (legume) weighted 134.15 g, whereas the control weighed 134.05 g, i.e., there were no significant differences. These results are in line with the results of bread made with the inclusion of 10, 15, and 20% of GBF, with 312.10, 318.93, and 320.47 g, respectively, whereas the control weighed 326.03 g, i.e., there were no significant differences. The weight of loaves is related to the techno-functional property of water absorption capacity

Table 3 Physical characteristics and instrumental colour of bread with different substitution levels

Components	Substitution level				
	0 (Control)	5%	10%	15%	20%
Moisture (%)	27.06 ± 2.06[a]	26.20 ± 2.00[a]	26.01 ± 2.06[a]	26.86 ± 2.23[a]	28.11 ± 3.65[a]
Weight (g)	326.03 ± 5.41[a]	307.27 ± 2.19[b]	312.10 ± 4.33[ab]	318.93 ± 4.69[ab]	320.47 ± 8.21[ab]
Height (cm)	11.58 ± 0.23[a]	8.38 ± 0.01[b]	8.53 ± 0.09[b]	7.66 ± 0.09[c]	7.19 ± 0.16[d]
Specific volume (cm³/g)	4.99 ± 0.07[a]	4.67 ± 1.66[a]	4.55 ± 0.04[a]	4.04 ± 0.16[a]	3.89 ± 0.11[a]
No. of gas cells	287.67 ± 51.47[a]	308.33 ± 30.90[ab]	397.83 ± 46.08[b]	338.67 ± 65.12[ab]	391.50 ± 102.82[ab]
Area occupied by gas cells (%)	18.92 ± 2.49[a]	23.34 ± 2.24[ab]	21.08 ± 4.63[ab]	26.51 ± 5.75[b]	24.68 ± 5.18[ab]
Baking weight loss (%)	12.29 ± 0.64[a]	13.60 ± 0.12[ab]	13.64 ± 0.92[ab]	13.62 ± 0.13[ab]	14.60 ± 0.44[b]
Instrumental colour					
L* (white to black)	76.06 ± 1.68[a]	65.89 ± 0.50[b]	63.86 ± 0.80[bc]	61.59 ± 0.74[c]	58.49 ± 1.27[d]
a* (red to green)	5.30 ± 0.24[a]	5.48 ± 0.44[b]	6.96 ± 0.67[b]	8.69 ± 0.63[c]	7.47 ± 0.64[c]
b* (yellow to blue)	24.42 ± 0.42[a]	23.31 ± 0.84[a]	23.47 ± 1.20[a]	25.37 ± 0.72[a]	23.92 ± 0.59[a]

Average ± standard deviation (n = 3: moisture, weight, height, specific volume, weight loss in baking, L*, a*, b*; n = 6: No. of gas cells and occupied area). Superscript with different letters in rows represent significant differences ($p < 0.05$). SL0 (control): 100% WF (wheat flour) + 0% GBF (germinated basul flour); SL5: 95% WF + 5% GBF; SL10: 90% WF + 10% GBF; SL15: 85% WF + 15% GBF; SL20: 80% WF + 20% GBF

[a] and [b] in rows represent significant differences

Fig. 1 Loaves and slices made with the following substitution levels: SL0 (control): 100% WF (wheat flour) + 0% GBF (germinated basul flour); SL5: 95% WF + 5% GBF; SL10: 90% WF + 10% GBF; SL15: 85% WF + 15% GBF; SL20: 80% WF + 20% GBF

of the flours at the time of kneading, and the retention of water during baking, both cases related to protein content (Olojede et al. 2020). Therefore, the high protein content of the basul may have played an important role in maintaining the loaves with an adequate weight during and after baking.

On the other hand, although there was a slight decrease in values of physical characteristics, such as specific volume, number of gas cells, and the area occupied by them (Table 3), these values did not differ significantly when wheat flour was substituted with GBF up to 20%. In this regard, it should be noted that one of the components that plays an important role in the techno-functional properties of the bakery industry is gluten (called forming proteins) of wheat, composed of gliadins and glutenins that represent around 75–80% of total protein. Gluten in wheat flour is responsible for the viscous and elastic nature necessary for the processing of the dough. In addition, it provides the three-dimensional protein matrix that prevents the diffusion of gas, and allows the formation and stabilisation of the gas cell walls in baked bread. For this reason, obtaining bread without the contribution of the properties of gluten is a considerable challenge (Sciarini et al. 2016). The results of the present study indicate that the high protein content of GBF could perform efficiently in the formation of the physical structure of bread. It is possible to affirm the viability including this flour, without affecting the physical quality of the product.

Instrumental colour of bread made with the inclusion of germinated basul flour

Table 3 shows the results for instrumental colour. Firstly, a progressive decrease in the luminosity of the loaves of bread was observed as the SL of wheat flour with GBF increased (SL0: L* = 76.06; SL20: L* = 58.49). These results can be contrasted with those of Fig. 1. The loaves of bread with the inclusion of GBF became darker or more opaque. The same fact had been observed in a study

conducted with cupcakes made with partial substitution of wheat flour with soy flour. As the SL increased, the samples became darker (lower L* value) (Paucar et al. 2016). Also, in bread made with inclusion of chickpea flour (0, 10, and 20%), the L* values were reduced from 64, without adding chickpea, to 48.54 with substitution of 20% (Yamsaengsung et al. 2010). In the case of bread with partial replacement of wheat flour with germinated cowpea flour (0, 5, 10, 15, and 20%), the colour of the crumb and crust became progressively darker as the bread contained higher replacement levels. L* values decreased from 71.76 in the control to 66.17 in breads of germinated chickpea.

Regarding a* values (indicating the variation from red + a* to green − a*), differences were also observed ($p < 0.05$). SL0 turned out to have a lower a* value in comparison to that observed in the treatments with the highest SL using GBF, in which bread tended to become more reddened. In the case of bread with germinated cowpea flour, the values of a* increased from 0.43 to 3.89, proportionally to the SL. Also, in cupcake samples with a higher proportion of soy flour, the redness increased (Paucar et al. 2016). Finally, with respect to b* value (ranging from yellow + b* to blue − b*), there were no differences between all the treatments and the control ($p < 0.05$). Apparently, the replacement with GBF did not generate changes in colour.

Sensory characteristics of bread made with the inclusion of germinated basul flour Flash Profile technique

The GPA of variance (PANOVA) summarises the efficiency of each transformation or permutation in the GPA in terms of reducing total variability. The translation ($F = 2.377$; p-value = 0.007), escalation ($F = -0.243$; p-value < 0.0001), and rotation ($F = 0.000$; p-value < 0.0001) stages indicate a preponderant impact in the reduction of the variability of the configurations, i.e., they had a significant effect on the contribution of permutation in the variability of the configurations.

Figure 2a, illustrates the residuals per consumer (evaluator) after the GPA. It was observed that the residue was greater for evaluator 17 (25.635), indicating that this evaluator was the furthest from the consensus. The attributes provided were significantly different from the attributes of the other evaluators. Similar behaviour was observed in evaluators 11 (10.559), 9 (17.416), 8 (9.314), 6 (15.140), 5 (16.465), and 1 (12.934). Furthermore, it could be observed that the residuals of the other evaluators were relatively similar to each other.

Figure 2b, allows visualising the factors of GPA. Consumer behaviour was divided into two groups, namely: the group with rescaling factor less than 1 (evaluators 2, 3, 4, 6,
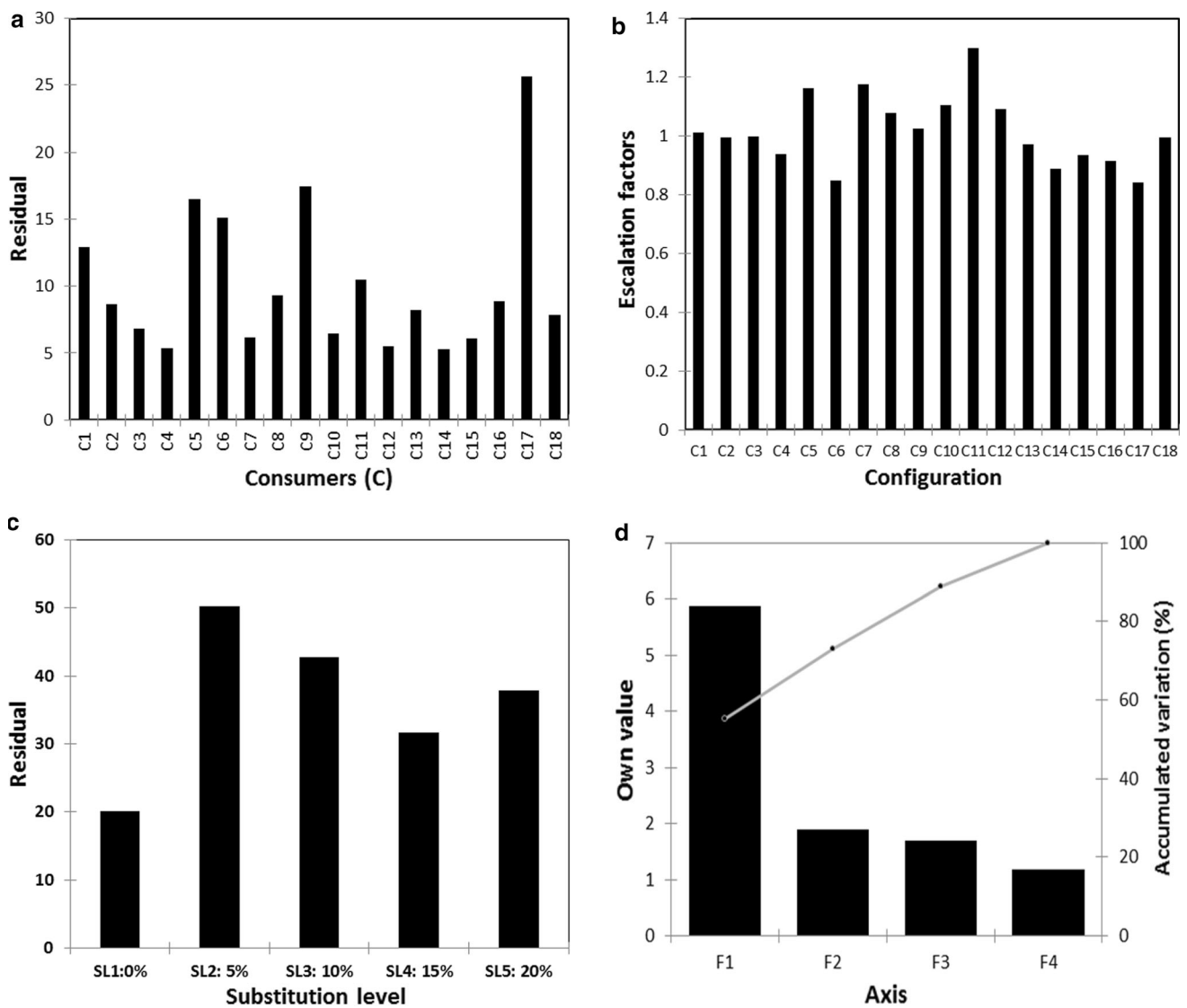
Fig. 2 **a** Residual per evaluator resulting from the GPA (generalised Procrustes analysis); **b** Rescaling factors for each evaluator; **c** Residual by substitution level, result of the GPA; **d** Variability (%) of own values and accumulated variability

13, 14, 15, 16, 17, and 18), who did not use such a large scale like the other evaluators and provided fewer sensory descriptors; and the group with a rescaling factor greater than 1 (evaluators: 1, 5, 7, 8, 9, 10, 11, and 12), which presented a greater number of descriptors and similar sensory attributes, unlike the previous group.

Assessment of the attributes reported by the evaluators

Five samples were assessed and the consumers (evaluators) generated their own vocabulary (attributes), obtaining a total of 118 attributes. Fifty descriptors were excluded in the final list of attributes, 38% of which corresponded to attributes relating to the sense of touch, 24% to the sense of

taste, 20% to the sense of smell, and 9% to the sense of sight.

The number of attributes obtained in the present study is greater than that reported in a study assessing chicken sausages, which found 37 descriptors of textural attributes. The same fact was reported in a study on Pleurotus mushroom sauce, in which only 14 descriptors had been agreed (Silva et al. 2016). The difference in the final number of sensory attributes may be related to the number of evaluators. Most of the studies have considered between five and nine evaluators, whereas the group of evaluators in the present study consisted of 18 consumers. Furthermore, Delarue and Sieffermann (2004) state that a group of consumers, being subjects without or with less training, use an entirely spontaneous varied vocabulary. The number of

descriptors could also depend on the product being assessed, in terms of appearance, smell, taste, and texture.

Sample assessment

Figure 2c, illustrates the residuals per sample after the GPA transformations. SL0 with 0% substitution obtained the weakest residual (20.099). This result indicates that the product was the subject of consensus, and there was no great difference between the evaluators' ratings for this formulation, i.e., they all perceived the samples in a similar manner. On the other hand, the greatest residual amount was obtained in SL5 formulation (5% GBF), with 50.283. Therefore, there was less agreement among the evaluators with respect to this sample.

The sensory attributes reported by the consumer evaluators were used in the GPA. The descriptors generated by the Flash Profile analysis were represented in two dimensions or axes (F1 = 55.280; F2 = 17.710), explaining 72.990% of the variability of the data (Fig. 2d). This value was slightly higher than that obtained by Dairou and Sieffermann (2002) with 69% variability in the comparison of 14 jams, as well as in the determination of sensory attributes of Creole turkey meat, with 67.90% variability (Ramírez et al. 2012). On the other hand, it was lower than that reported by Rodríguez-Noriega et al. (2021) in the characterisation of flour tortillas, with 83.78%.

Figure 3a, illustrates the position of the samples in the sensory space. Three groups were formed in dimensions F1 and F2 (72.99%), in which SL5 formulations with 5 and 10% substitution were similar to each other. Also the formulations with 15 and 20% substitution exhibited similar behaviours between them. On the other hand, the treatment

with 0% substitution was different from the rest of the samples under study.

Figure 3b shows the sensorial space of attributes generated by the team of evaluators in dimensions F1 and F2 (72.99%). Considering Fig. 3a (sample sensory space), it is possible to observe the sensory differences between groups of formulations, and the attributes or descriptors that characterised them.

According to Kobayashi and Benassi (2012), only the descriptors with correlation coefficients equal to or greater than 0.60 (absolute value), and at the same time cited by various consumers, should be used to visualise the relationships between the formulations and the attributes. This way, the first dimension is mainly related to colour differences between treatments (opaque colour, light colour, black spots), flavour (sweet and grassy flavour), and appearance (spongy). The second dimension was better explained with terms relating to texture (hard and sticky).

The SL0 formulation, positioned in the negative zone of dimension 1, and in the positive zone of dimension 2, was characterised by the attributes sweet taste, sticky texture, and spongy appearance.

The formulations with 5 and 10% substitution (positioned in the negative zone of dimensions 1 and 2, and in the positive zone of dimension 1 of sensory space) were characterised by the attributes colour, such as light colour and black dots, sweet and grassy flavour, as well as sticky, with hard texture and spongy appearance. Unlike in SL0, it was possible to observe the presence of black dots, grassy flavour, and hard texture resulting from substitutions with low percentages of GBF.

Treatments with 15 and 20% substitution, positioned in the positive zone of dimensions 1 and 2, were characterised by the attributes sweet taste, black dots, opaque colour,

Fig. 3 **a** Sensory space of samples; **b** Sensory space of attributes or descriptors (colour figure online)

sticky texture, and spongy appearance. This way, as the percentage of substitution with GBF increased, the loaves of bread were increasingly characterised by opaque colour and black dots; however, the sweet flavour and spongy appearance were maintained. There was no grassy flavour or hard texture. For this reason, it was possible to affirm that these samples exhibited better behaviour than those with 5 and 10% substitution, with the exception of colour.

Conclusion

Bread formulated replacing 20% of wheat flour with GBF improved the nutritional composition, mainly in protein and crude fibre contents, which are nutrients required in healthy products, and reduced carbohydrate content. With this same formulation, the physical characteristics of bread related to weight, specific volume, and porosity were not substantially affected. Contrarily, from the sensory point of view, they were rated with the best flavour and appearance of the product, except for colour. All of them were compared with a control formulation containing 100% wheat flour. Bread with the inclusion of GBF has a high content of protein and fiber and low carbohydrates, which can be considered as an alternative for the prevention of some non-communicable diseases such as for overweight, obesity, and type II diabetes. However, further studies in vitro and animal model (in vivo) recommended.

Author contributions FVP and GChQ were responsible for conceiving the idea, designed the experiments and wrote the manuscript. CNCO and YVS conducted the experiments and analyzed the data. VHSC contributed to the data preparation, data analyses, and revised the manuscript.

Declarations

Conflict of interest The authors declare no conflict of interest.

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