

Original article

How does the replacement of rice flour with flours of higher nutritional quality impact the texture and sensory profile and acceptance of gluten-free chocolate cakes?

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Summary Gluten-free bakery products usually use rice flour as substitute for wheat flour. This paper aims to evaluate whether and how the substitution of rice flour for sorghum and teff flour changes the overall acceptance, texture and sensory profile of gluten-free chocolate cakes. An experimental design composed of three factors (rice, sorghum and teff flours) was developed, and formulations were analysed by acceptance test and fibre content. Four formulations were submitted to sensory descriptive analysis. The formulations did not show significant differences in the overall acceptance although the sensory profile has changed. The texture was affected by the type of flour, being the optimised formulation the softer among the samples. From these data, it can be concluded that it is possible to replace rice flour with sorghum and teff flour in chocolate cake formulations, since the change in the sensory profile did not affect the acceptance of the products.

Keywords Celiac disease, flash profile, gluten-free cakes, sorghum (*Sorghum bicolor* (L.) Moench), teff (*Eragrostis tef*).

Introduction

Celiac disease is defined as an autoimmune disorder that impairs the gastrointestinal system and affects about 1% of the world's population. The disease has many clinical manifestations, ranging from severe malabsorption to minimally symptomatic or non-symptomatic presentations. Therefore, the only treatment for celiac disease is the definitive exclusion of gluten from the diet (Lebwohl *et al.*, 2018).

Gluten is a protein present in most cereals such as wheat, barley and rye. The differences among the types of grains are based on the proportion of proteins present in them, such as glutenins, which provide elasticity and cohesion to batter, and gliadins, responsible for fluidity, extensibility and expansion (Balakireva & Zamyatnin, 2016), which are very relevant properties for baking. However, some cereals like rice, sorghum

and teff (Rosell *et al.*, 2014), pseudocereals such as amaranth, quinoa, and buckwheat (Krupa-Kozak *et al.*, 2011; Torbica *et al.*, 2012; Costantini *et al.*, 2014; Giménez-Bastida *et al.*, 2015; Turkut *et al.*, 2016) and seeds such as linseed and chia have none or little of these gluten-forming proteins (Steffolani *et al.*, 2014; Korus *et al.*, 2015).

The low global quality of gluten-free products and the growing number of patients diagnosed with celiac disease have led to the investigation of new ingredients and formulations to obtain gluten-free products as similar as possible to wheat-based products like breads (Marti *et al.*, 2017; Viell *et al.*, 2020), cookies (Torbica *et al.*, 2012; Sakač *et al.*, 2015; da Silva & Conti-Silva, 2018) and cakes (Marston *et al.*, 2016; Gao *et al.*, 2018; Salehi, 2019). Rice flour (*Oryza sativa* L.) is the main ingredient in gluten-free bakery products, since it has a neutral taste and odour, is affordable and easy to find. However, like the rice grain, its flour has a

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low nutritional value, consisting basically of starch and smaller amounts of proteins, lipids, fibres and ashes (Torbica *et al.*, 2012). Thus, Capriles & Arêas (2014) suggest the use of alternative ingredients to improve the nutritional value and diversify the gluten-free baked goods. Sorghum (*Sorghum bicolor* Moench) and teff (*Eragrostis tef*) cereals are great alternatives for this purpose. Sorghum is a staple food for more than half a billion people in at least thirty countries (FAO, 2012). It brings health benefits due to the presence of bioactive compounds such as fibres and phenolic compounds, which contribute to the proper functioning of the human organism (McCann *et al.*, 2015). Teff (*E. tef*) is also a gluten-free grain with high nutritional value. It is a cereal of Ethiopian origin rich in carbohydrates and fibres in addition to having in its composition more zinc, iron and calcium than other grains such as wheat and rice (Campo *et al.*, 2016). Some studies have evaluated the use of teff in gluten-free foods or as a partial substitute for wheat. However, some of such studies only reported the impact of teff utilisation on the texture and nutritional properties of products (Marti *et al.*, 2017; Zhu, 2018).

A product that has excellent chemical, physical, nutritional, or microbiological characteristics is worthless to the consumer, if the sensory characteristic of this product does not fulfil the needs and desires of those who will consume it. The quality of a food implies, among other factors, consumer satisfaction and it is up to him to define the quality parameters of the product (Vad Andersen & Hyldig, 2015; Andersen *et al.*, 2019). Descriptive sensory analysis provides the mapping of similarities and differences between products and helps in determining the attributes that are important for acceptance. The results allow to relate a specific ingredient, with specific changes in the sensory attributes of a product (Stone & Sidel, 2004).

Given the facts exposed, the objective of this research was to optimise a gluten-free chocolate cake formulation and to evaluate the changes promoted in the texture, and sensory profile and acceptance of these cakes when replacing rice flour with sorghum and teff flours.

Material and methods

Ingredients

The chocolate cakes were made with whole-grain flours of brown sorghum (Farovitta®) and red teff (Giroil®), and refined rice flour (Terra Verde®) flour. The remaining ingredients used in the formulations were obtained from the local market of Campo Mourão, Paraná, Brazil. Reagents by analytical standard were supplied by Sigma-Aldrich (St Louis, MI, USA).

Experimental design

The experimental design was based on a gluten-free chocolate cake formulation made with rice flour (F1). This formulation was composed of milk with 3.0% fat (40.24%), sugar (20.12%), rice flour (11.78%), soybean oil (7.80%), cocoa powder (7.56%), eggs (6.10%), potato starch (3.94%), cassava starch (1.96%), baking powder (0.18%), xanthan gum (0.12%), sodium bicarbonate (0.12%) and salt (0.06%). F1 can be considered as a standard formulation, since it is composed only of rice flour, basic ingredient of most gluten-free bakery products.

From this basic formulation, a mixture planning was developed to make partial and total substitutions of the rice flour for sorghum and teff flour. The experimental design was the Simplex Centroid ($2^3 - 1$) composed of three factors (rice, sorghum and teff flours) and repetition at the central point (Cornell, 2011), as shown in Table 1.

For the fibre quantity response variable, a linear model was fitted (eqn (1)) using the fibre content of each flour. For the overall acceptance variable, a special cubic model was fitted (eqn 2). Statistical analyses were performed using software Statistica 12.1 (StatSoft, Inc., Tulsa, OK, USA).

$$y = b_1x_1 + b_2x_2 + b_3x_3 \quad (1)$$

$$y = b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{123}x_1x_2x_3 \quad (2)$$

The variables x_1 , x_2 and x_3 correspond, respectively, to rice, sorghum and teff flour, substituted in Table 1 by R, S and T.

Sample production

The eggs were homogenised in a planetary mixer SX84 (Arno, São Paulo, Brazil) at high speed (11 303 g) for 3 min. Milk and soybean oil were added and homogenised for 5 min. Next, the dry ingredients (except the baking powder) were added and mixed for 3 min. Then, the baking powder was added and incorporated into the batter, which was transferred to aluminium pans (22 × 10 cm) and baked (180 °C/ 33 min). Each pan was filled with 450 g of dough. After being removed from the oven, the cakes remained at room temperature (25 °C) until completely cool and were packed in polyethylene bags until the time of the other analysis.

Microbiological analysis

The samples were analysed for fecal coliforms and counts of total coliforms and *Salmonella* spp in 25 g using the BAX system method from the U.S. Food

Table 1 Experimental design for gluten-free chocolate cake formulations according to the sensory attributes and statistical models for mixing properties

F	Rice	Sorghum	Teff	Colour	Odour	Texture	Flavour	Overall acceptance	Fibre (%)
F1	1.00	0.00	0.00	7.89 ^a ± 0.14	7.28 ^{abc} ± 0.18	7.71 ^a ± 0.15	7.85 ^a ± 0.14	7.83 ^{ab} ± 0.13	4.91
F2	0.00	1.00	0.00	7.92 ^a ± 0.13	7.42 ^{ab} ± 0.17	7.72 ^a ± 0.16	7.78 ^a ± 0.15	7.83 ^{ab} ± 0.14	5.71
F3	0.00	0.00	1.00	8.08 ^a ± 0.12	6.75 ^d ± 0.21	7.12 ^a ± 0.20	7.54 ^a ± 0.15	7.52 ^{ab} ± 0.14	6.21
F4	0.50	0.50	0.00	7.91 ^a ± 0.14	7.55 ^a ± 0.14	7.65 ^a ± 0.14	7.52 ^a ± 0.15	7.71 ^{ab} ± 0.13	5.38
F5	0.50	0.00	0.50	7.91 ^a ± 0.12	6.68 ^d ± 0.19	7.31 ^a ± 0.15	7.35 ^a ± 0.15	7.48 ^{ab} ± 0.13	5.85
F6	0.00	0.50	0.50	8.00 ^a ± 0.11	7.00 ^{bcd} ± 0.20	7.50 ^a ± 0.16	7.49 ^a ± 0.15	7.57 ^{ab} ± 0.14	6.35
F7	0.33	0.33	0.33	8.03 ^a ± 0.12	7.60 ^a ± 0.16	7.82 ^a ± 0.15	7.89 ^a ± 0.13	8.03 ^a ± 0.11	5.63
F8	0.33	0.33	0.33	7.91 ^a ± 0.13	6.95 ^{bcd} ± 0.20	7.26 ^a ± 0.17	7.38 ^a ± 0.16	7.55 ^{ab} ± 0.14	5.63
F9	0.33	0.33	0.33	7.86 ^a ± 0.14	6.82 ^{cd} ± 0.19	7.21 ^a ± 0.16	7.41 ^a ± 0.16	7.32 ^b ± 0.14	5.63
Equation				7.89R + 7.92S + 8.08T	7.27R + 7.42S + 6.75T	7.71R + 7.72S + 7.12T	7.85R + 7.78S + 7.54T	7.84R + 7.83S + 7.52T	4.95R + 5.78S + 6.37T
R ²				0.72	0.75	0.58	0.52	0.75	0.89
P				0.24	0.01	0.11	0.14	0.04	—
Lack of fit				0.12	0.03	0.18	0.5	0.03	—

Means in the same column followed by distinct letters differ according to the Tukey test ($P < 0.05$).

R, rice flour; S, sorghum flour; T, teff flour.

and Drug Administration's Bacteriological Analytical Manual (Feng *et al.*, 2002; Andrews *et al.*, 2007). These analyses are those established by Brazilian legislation (ANVISA, 2001).

Acceptance test

All the cake formulations were submitted to an acceptance test, evaluating the attributes of overall acceptance, colour, flavour, aroma and texture using a 9-point Hedonic Scale (9-liked extremely; 1-disliked extremely) (Stone & Sidel, 2004). The tests were applied on three consecutive days in the university's sensory analysis laboratory, with 100 untrained assessors, and all the panellists participated in the 3 days and evaluated all samples. Each assessor was given a pre-screening form to obtain information about age, gender, education completed, frequency of cake consumption, and potential food allergies. Assessors signed an informed consent form to notify them about the purpose and guidelines of the study.

In each sensory analysis session, assessors received three samples, one of which was the repetition of the centre point (33.3% of each flour type, F7, F8 and F9) and two other samples chosen randomly from the six formulations that make up the experiment (F1, F2, F3, F4, F5 and F6). Cake samples cut into cubes (2.5 cm²) were served in plates coded with three random digits, in monadic and random order. Samples were always served to assessors 18 h after production. This time was standardised in all sensory analysis sessions to avoid differences between samples due to changes that could occur in the cakes due to the storage time.

Evaluation of fibre content

Fibre content of each cake formulation was calculated indirectly, using the fibre content of each raw material provided by the Food Composition Database of the United States Department of Agriculture (USDA, 2015). Fibre contents of the rice, sorghum and teff flours, and the data were based on laboratory analyses (method 991.43) (AOAC, 2005). From these values and the amount of each ingredient present in each formulation, the fibre content of products was calculated.

Formulation optimisation

After the statistical evaluation of the proposed models, the equations were combined to find the optimum proportion of the rice, teff and sorghum flours using the desirability function (Barros Neto *et al.*, 2010). This approach involves transforming each estimated response variable y_i into a desirable value d_i , where $0 \leq d_i \leq 1$. As in the optimised formulation the objective was to use y_i as a maximum value, both for

the fibre and for the global impression, eqn (3) was used.

$$d_i(y_i(x)) = \begin{cases} 1 & \text{se } y_i(x) < L_i \\ \left[\frac{U_i - y_i(x)}{U_i - L_i} \right]^t & \\ 0 & \text{se } y_i(x) > U_i \end{cases} \quad (3)$$

The individual desirability values (d_i) should then be combined to form the general desirability (D), given by eqn (4).

$$D = \sqrt[n]{d_1 d_2 d_3 \dots d_m}, \quad (4)$$

with the formulation optimisation process, only four formulations were submitted to the other evaluations proposed in this research: F1 (rice), F2 (sorghum), F3 (teff) and FO (optimised formulation), according to Figure S1.

Flash profile

Four cake formulations were submitted to sensory descriptions by the Flash Profile method (Dairou & Sieffermann, 2002), F1, F2, F3 and FO (optimised formulation), which presents the highest overall acceptance and fibre content.

The assessors (12) were selected in compliance with ISO Standard 8586:2012 (ISO, 2012). Then the survey of descriptive attributes was performed, in which assessors tasted the cakes regarding similarities and differences in appearance, aroma, flavour and texture. Each assessor was assisted in developing the descriptive terms, recording and describing them. These descriptive terms were used to elaborate the personalised sensory evaluation form. Samples (2.5 cm²) were presented to the assessors, who were asked to taste and rank them in ascending order, according to the intensity of each attribute. The analyses were performed in triplicate on three alternating days. The results for each assessor were plotted in an array (attributes in the columns and samples in the lines). The data analysis was performed using software MATLAB R2008b and the ComDim technique, according to the algorithm proposed by Qannari *et al.* (2001) and described in detail by Jouan-Rimbaud Bouveresse *et al.* (2011). The application of this method to this type of analysis was described by Fuchs *et al.* (2018).

The Ethics Committee of the Federal University of Technology – Paraná approved all sensory evaluations (acceptance test and Flash Profile) under protocol number 88116618.2.0000.5547.

Texture profile analysis (TPA)

Cakes, without the crust, were cut into cylindrical pieces with diameter of 36 mm using a stainless-steel

cutter. Samples were subjected to a double cycle of compression in a TA-TX/Express Enhanced Texture Analyzer (Stable Micro Systems, UK). For that, a cylindrical P/36R probe (36 mm diameter) compressed 30% of the original cake height at a speed of 2 mm s⁻¹. Seven samples of each treatment were evaluated.

The parameters evaluated were hardness, springiness, chewiness, cohesiveness and resilience (Moscatto *et al.*, 2004). The results determined for each parameter were obtained directly from the software associated with the texture analyzer (Expression PC), and such data were analysed using the ANOVA and Tukey test ($P < 0.05$).

Results and Discussion

Acceptance test and fibre content

All formulations presented Coliforms values below the limits established by Brazilian legislation RDC n^o. 12 (ANVISA, 2001), besides the absence of *Salmonella* spp in 25 g samples, showing that the cakes are suitable for human consumption.

A total of 100 assessors participated in the acceptability study including fifty-nine females and forty-one males. The age of assessors ranged from 18 to 44 years with 65% of assessors in the eighteen to twenty-five age group. For cake consumption, 61% assessors claimed to eat cake at least once a month, while 39% consumed cake at least once every 2 weeks. The results demonstrated that 60% of respondents claimed they may purchase gluten-free products, while 15% claimed they would buy and 25% they would not buy gluten-free products. Table 1 presents the values obtained from the analysis of variance as a function of sensory attributes of each formulation.

The cake samples did not differ significantly for colour, texture and flavour attributes, but there are differences in aroma and overall acceptance attributes. The aroma score varied from 6.68 to 7.60. The values found for the acceptance of odour of cakes containing sorghum in this study were higher than those found by (Marston *et al.*, 2016), which revolved around 6.2. Formulations F4 and F7 had the highest acceptance regarding this attribute, while formulation F5 showed the lowest approval. Thus, the best acceptance concerning the aroma is associated with the presence of sorghum flour in the formulations, with rice and teff flour making the aroma of the formulations less acceptable. This positive impact of sorghum on the odour of cakes was also verified by (Marston *et al.*, 2016) as well as the negative influence of teff flour on this attribute was observed by (Mohammed *et al.*, 2009) who evaluated the replacement of wheat flour by teff flour in breads.

Regarding the overall acceptance, there was a variation from 7.32 to 8.03. Formulations F7 and F9, despite being repetitions of the central point, showed a significant difference. F7 presented the most expressive overall acceptance (8.03), while F9 received the lowest (7.32). This may be because they were analysed on different days and, in sensory analysis, the measuring instrument is the human sensory perception, which may vary individually and undergoes constant modifications. Figure 1 presents the overall acceptance that the 100 assessors reported in the sensory analysis. The percentage of those who liked the product was high for all formulations proposed, with F7 and F9 being the 100% grades comprised between 6 and 9 on the hedonic scale. The F3 formulation showed the highest rejection (3.5%) and the neutrality (4.5%).

The fibre content of each formulation ranged from 4.91% (F1) to 6.35% (F6). This result was expected since the sorghum and teff flours contain more fibre than rice flour. Table 1 presents the adjusted models

and corresponding statistical quality parameters obtained from the experimental. Non-significant effects were excluded in the models. The significant attributes for the optimisation would be odour, and overall acceptance, the latter showing a statistically significant correlation with odour, thus explaining 72% of the data. Therefore, due to this direct correlation and the better capacity of this parameter, only the general overall acceptance model was used in the optimisation step along with the fibre content of each formulation.

The coefficients of the colour, aroma and texture models indicated that the chocolate cake formulations containing sorghum flour showed greater acceptance for such attributes, while the coefficients of the flavour and overall acceptance models showed that the cakes containing rice flour had higher acceptability regarding such sensory attributes. Also, the fibre model showed that the presence of teff flour in the formulations increases fibre content.

The contour plots of the response surfaces for colour, aroma, texture, taste, overall acceptance and fibre

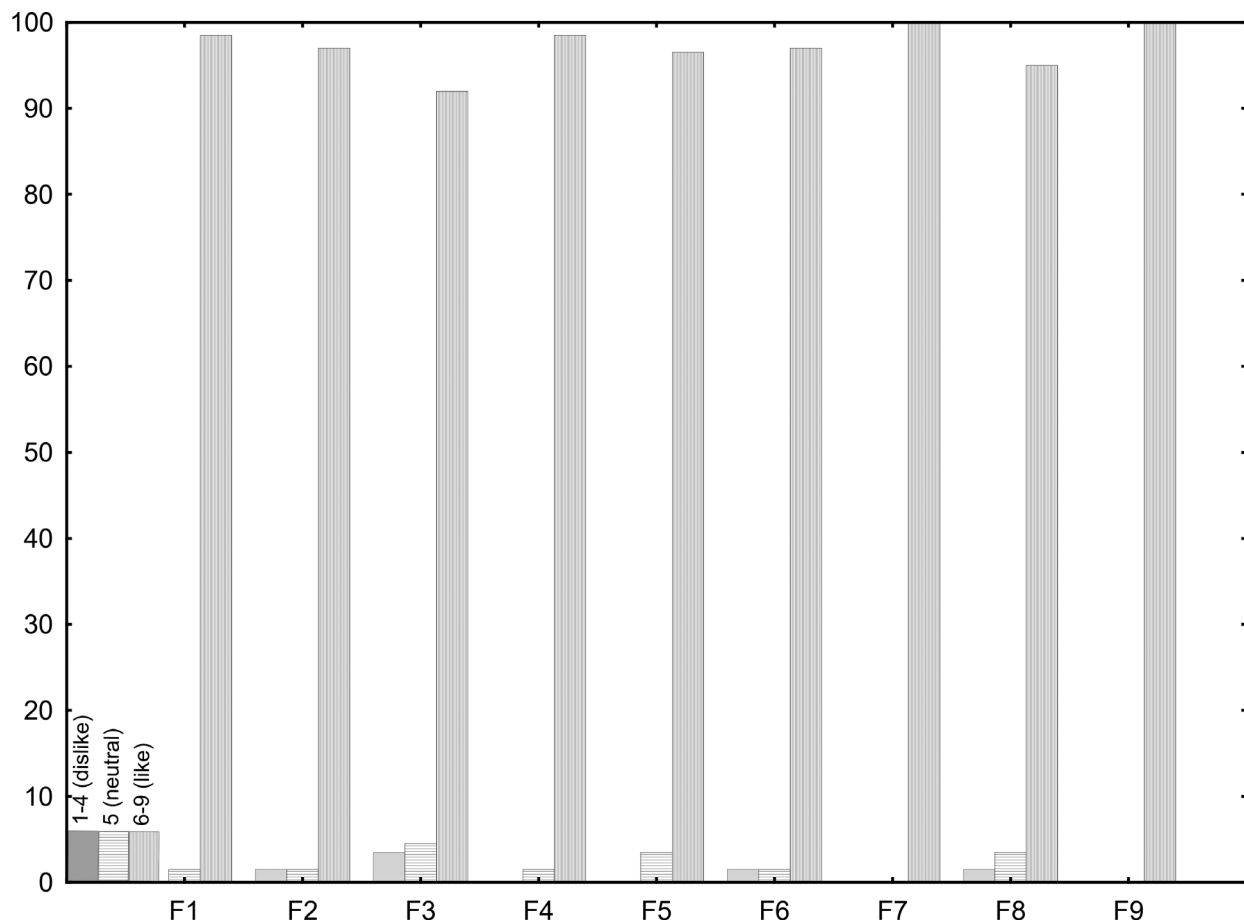


Figure 1 Overall acceptance according to classification 1–4 (dislike), 5 (neutral) and (6–9) (like) in the hedonic scale for the cake formulations.

content with variations in the flour types and proportions in the formulations may be visualised in Fig. 2.

In the surface contour for colour, higher concentrations of teff flour combined with a little sorghum flour increase the acceptance of this attribute in the formulations, and, as rice flour is added, the approval of the colour decreases. Thus, for a better contribution to the colour aspect of the chocolate cakes, a 75:25 mixture of teff and sorghum flours increase the acceptance of the evaluated attribute.

Regarding the evaluated aroma attribute of the formulations, the response surface contour indicates that the presence of more sorghum flour increases its acceptance, including formulations using less than 50% of rice flour. Teff flour does not contribute positively to this attribute, given that, as its proportion increases in the formulations, the aroma scores decrease.

The graph for the texture attribute indicates that the sorghum flour contributes the most to its acceptance, but rice flour still contributes to a pleasant texture, as well as a 75:25 combination of sorghum and teff flour.

As can be observed on the response surface contour, formulations containing 100% of either rice or sorghum flour showed greater acceptance in the flavour attribute, and even mixtures of 75:25 rice and teff flour or of sorghum and teff flour still maintained good approval for this attribute.

In the fibre surface contour, one may notice that more expressive amounts of teff flour provide an increase in the fibre content of the cakes, which decreases with the addition of rice flour. Thus, a 50:50

mixture of teff and sorghum flours yields a formulation with higher fibre content. It may be observed in the overall acceptance surface contour that the higher the sorghum flour content in the formulations is, the better the overall acceptance of the cakes is, unlike for teff flour, whose concentration increase in the formulations causes a decrease in the overall acceptance. Through the overall acceptance response surface contour, a 50:50 blend of rice and sorghum flours, and even proportions below 25% of teff flour, generate a more significant overall acceptance for the formulations.

Figure 3 shows the desirability function, where the individual desirability values of the experimental data are shown with their minimum and maximum variations along with the overall desirability, which represents the percentages of the rice, sorghum and teff flours in the mixture for an optimal formulation. Through this function, the optimised formulation would have an estimated overall acceptance of 7.5945 and a fibre content of 5.9463%, which may be observed through horizontal blue lines on the graph. The optimised formulation considered the higher amount of fibre and the best overall acceptance considering the three flours: 16.7% of rice flour, 35.8% of sorghum flour, and 47.5% of teff flour. The optimal point for each flour type may be observed through vertical red and dashed lines.

Subsequently, the optimised formulation was prepared and subjected to the overall acceptance test with 100 untrained assessors. The overall acceptance for

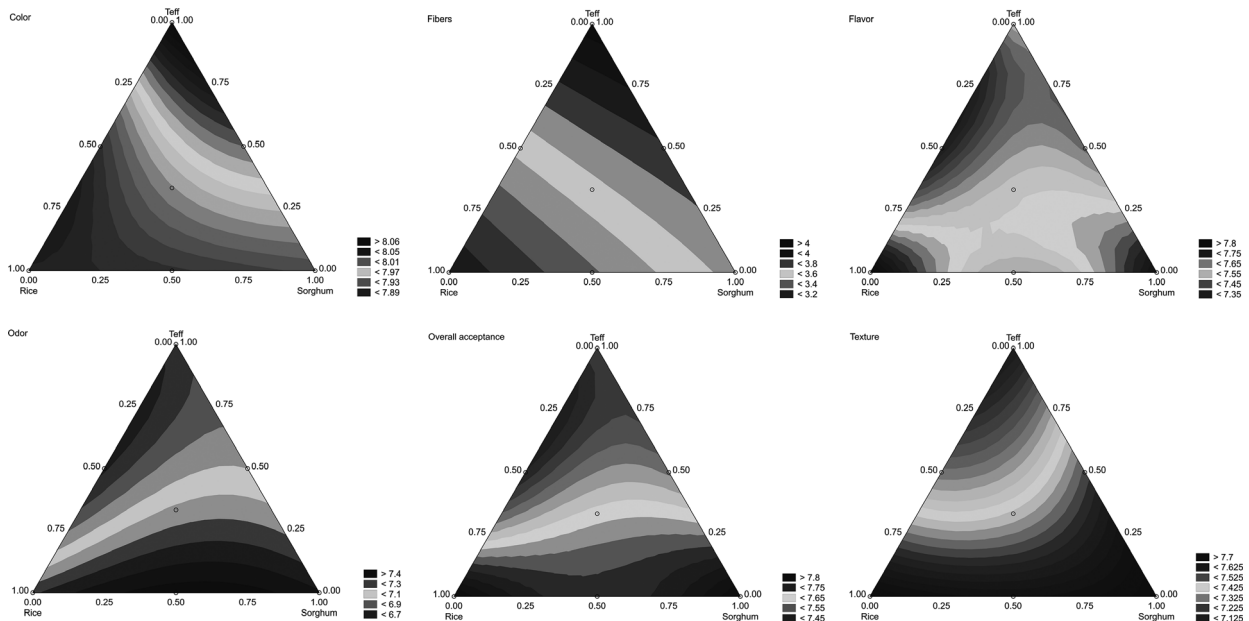


Figure 2 Contour plot of the response surfaces for colour, aroma, texture, taste, overall acceptance and fibre content.

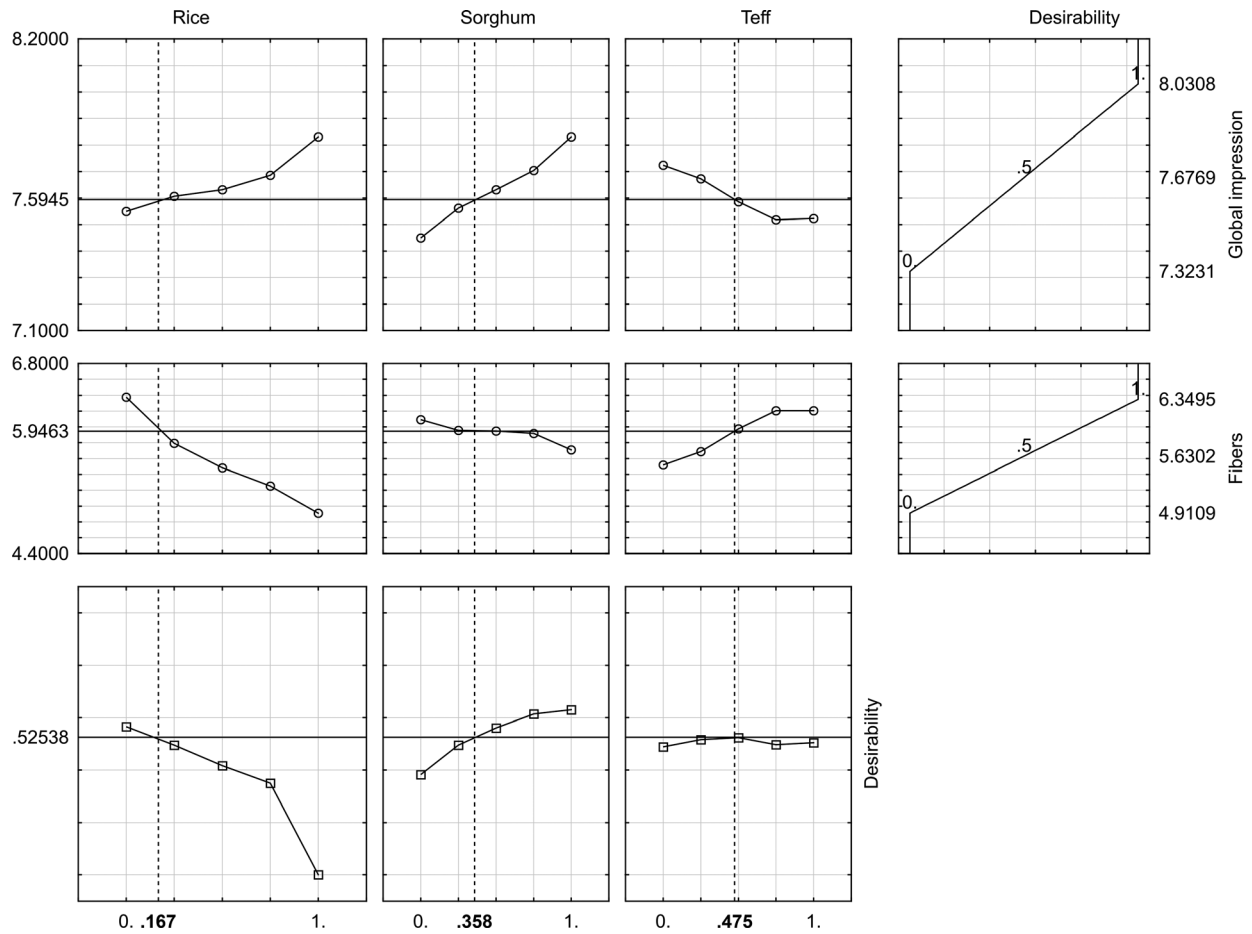


Figure 3 Graph of the desirability function.

this formulation was 7.70, slightly higher than the value estimated by the optimisation (7.5945).

Flash profile

The panel consisted of twelve assessors (A1 to A12). Cake formulations (F1, F2, F3 and FO) were submitted to sensory descriptions through the Flash Profile, in triplicate (R1–R3). The Flash Profile ordering data were analysed by the ComDim method, and, thus, the consensus distribution of the assessors was obtained. From this output, two common dimensions (CD1 and CD2) were determined as the most important, explaining 85.3912% of the data variance, as shown in Fig. 4a.

Figure 4a shows that some of the formulations are well segmented and that there was reasonable reproducibility among the replicates. It is noted that F1 (rice) and F2 (sorghum) are quite distinct. Rice flour has mild sensory aspects, making it possible to make

cakes without very distinctive characteristics, unlike F2, which is composed exclusively of sorghum, a type of flour with more pronounced sensory characteristics. It may also be verified that F3 (teff) and FO are more similar to each other, a fact justified by the types and concentrations of flours present in such formulations.

Figure 4b shows the salience of each assessor for each common dimension, that is, the weight associated with each assessor for the formation of each common dimension. Assessor A6 is the most important for the construction of CD1, while A5 is the one that most contributes to the formation of CD2. The analysis of the salience also allows identifying the assessors who could not discriminate among the samples, that is, those that have low salience in all the most relevant common dimensions (Qannari *et al.*, 2001), and the assessors A4 and A11 presented low salience values for both dimensions. The statistically significant correlations among the common dimensions and the attributes of the assessors are listed in Table 2.

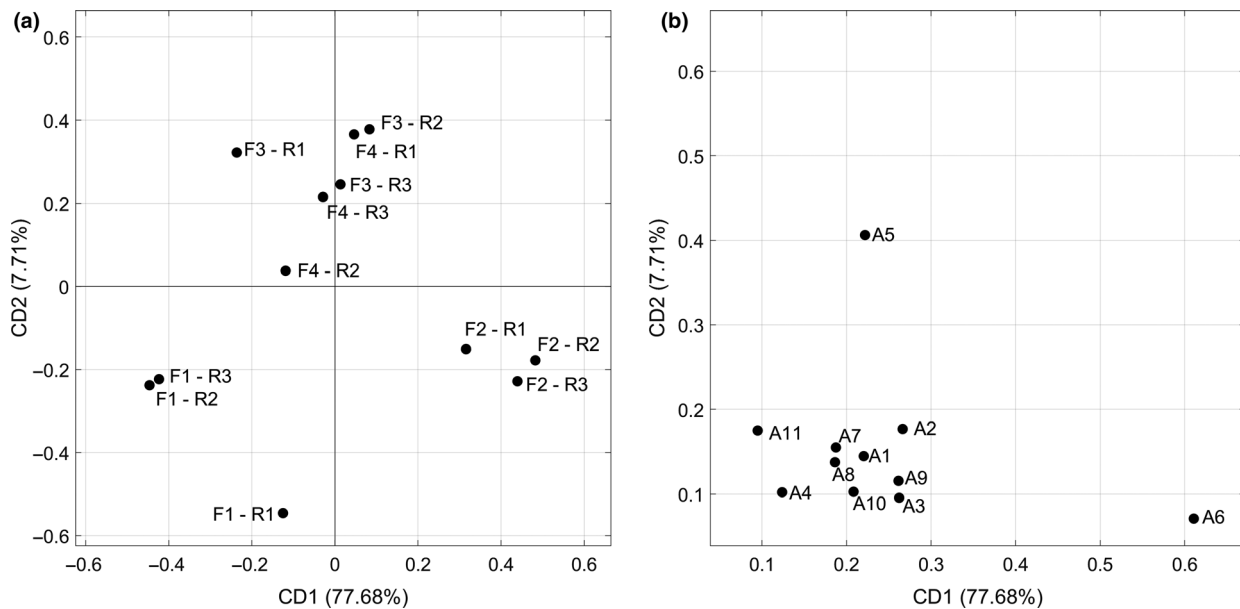


Figure 4 Graph of sample consensus (a) and assessors' salience regarding common dimensions 1 and 2 (b).

Formulation F1 (rice) is in the negative quadrants of CD1 and CD2, showing that it is a sample with a less intense brown colour, less moisture, a more intense chocolate aroma, and little brightness and elasticity. These characteristics are typical of the presence of rice flour, which has a lighter colour than the others and usually yields characteristics of lower moisture and plasticity in baking products, as well as a neutral aroma, allowing the prominence of the chocolate aroma in the formulation (Rosell & Marco, 2008; Conte *et al.*, 2019).

Table 2 Significant correlations ($P < 0.05$) among the common dimensions (CD) and the sensorial attributes raised in the Flash Profile

Correlations with CD1		Correlations with CD2	
Negative	Positive	Negative	Positive
Chocolate aroma (4)	Brown Colour (8)	Chocolate flavour (3)	Sweetness (2)
Aerated (1)	Moisture (5)	Cocoa aroma (2)	Whole cereal aroma (2)
Rancidity (1)	Brightness (3)	Sweetness (1)	Chocolate flavour (1)
Flour flavour (1)	Elasticity (2)	Aerated (1)	Wheat flour aroma (1)
	Aerated (1)	Yeast flavour (1)	
	Creaminess (1)		
	Whole cereal aroma (1)		
	Bitterness (1)		

Formulation F2 (sorghum) is in the positive quadrant of CD1 and negative of CD2, being characterised as a darker brown cake (pertaining to the darker flour), higher moisture, brightness and elasticity, as well as a less intense chocolate aroma due to the sorghum flour having a distinctive smell that masks the chocolate aroma.

Formulations F3 and FO are close to the origin of CD1 and in the positive quadrant of CD2. Therefore, the sweetness and the presence of a whole-grain aroma, which is related to the presence of teff flour, may be designated as attributes that characterise these formulations. Teff flour also made the whole-grain aroma attribute used to describe breads where this flour was incorporated (Viell *et al.*, 2020). F1 and F2 have a more intense chocolate flavour than F3 and FO, suggesting that the teff flour has a very intense flavour, which, according to the assessors, decreased the taste of chocolate in the F3 and FO cakes.

Despite the substitution of rice flour for sorghum flours, teff or combinations of these in chocolate cake, promoting major changes in the sensory profile of the products, the overall acceptance among them varied little (7.52–7.83). As rice flour is removed from the cake formulations and flours of sorghum and teff are added, the product is no longer characterised as light coloured, dry, inelastic and with an intense chocolate aroma, but is characterised by a more intense brown colour, greater humidity, bright, elasticity, whole foods aroma and less intensity in chocolate aroma. This maintenance of overall acceptability despite the change

in the product's descriptive profile is very favourable, as it suggests that consumers may be more used to and appreciate the sensory characteristics provided by whole ingredients, enjoying the health benefits that these products offer.

Texture profile analysis (TPA)

Cake formulations present significant differences for all parameters evaluated, as can be seen in Table 3.

The highest value obtained for hardness was found for formulation F1, followed by F2, FO and F3. The same behaviour was detected for chewiness, given that the tougher the cake is, the more energy is required to break it down (Osawa *et al.*, 2009). These results may be associated with the highest moisture content found for the FO and F3 formulations. According to Witczak *et al.* (2016), the exact behaviour of starch, when processed by the heat-moisture treatment, depends highly on its origin, but also on non-starch substances present in the flour which could be involved in its stabilisation, such as hydrocolloids, surfactants and other water-soluble molecules. Hager *et al.* (2012) reported that a lower hardness is preferred since consumers tend to associate a tough crumb with an old product. This is an advantage of the optimised formulation compared to the others, given that a reduced hardness value was found mainly due to its flour composition.

Elasticity is described by springiness and resilience, with a reduction in either one characterising a loss of elasticity (Onyango *et al.*, 2011). F1 and FO presented the highest results for both parameters, although they are considered statistically different for the resilience parameter.

The lowest elasticity value was found for F2 sample. It is known that a batter's elasticity is related to the presence of glutenins, constituents of the gluten protein (Balakireva & Zamyatnin, 2016). In their absence, other proteins may contribute to the elasticity of the batter. One may observe that, among the flours assessed in this study, sorghum flour is the one with the highest protein percentage (Table 3), yet this was

not enough to guarantee higher springiness or resilience.

Another parameter obtained from the TPA analysis is the cohesiveness, which measures the strength of the internal bonds that define the structure of the food. In cakes, cohesiveness is the textural parameter that evaluates the rate of breakage in the mouth and easy separation on the hand (Miñarro *et al.*, 2012). The optimised formulation presented an intermediate value when compared to the other samples, and the cake made only with rice flour (F1) showed the highest cohesiveness value.

Conclusion

The data show that it is possible to substitute rice flour, traditionally used in gluten-free products, for sorghum and teff flour in chocolate cakes, with the use of the latter increasing the fibre content of the products. The overall acceptance of the products made with the different flours practically does not change, but it was verified that the aroma is adversely affected by the addition of teff flour. Thus, the amount added of this variable must be limited.

It was possible to characterise gluten-free chocolate cake using the Flash Profile. The sample containing only rice flour showed less intense brown colour, lower moisture, brightness and elasticity, as well as a more intense chocolate aroma. The cake formulated with sorghum flour showed more intense brown colour, greater moisture, brightness and elasticity, as well as a milder chocolate aroma. The formulation made only with teff flour is similar to the optimised formulation, characterised by sweetness and a more pronounced whole-grain aroma.

The texture properties evaluated were significantly affected by the flour type, with the optimised formulation being considered the less tough and more elastic and cohesive among the samples.

It was verified that the substitution of rice flour for sorghum and teff flour did not change the overall acceptance of the cake formulations despite the great

Table 3 TPA of gluten-free cake formulations

Parameters	Formulations			
	F1	F2	F3	FO
Hardness (N)	14.83 ^a ± 0.39	13.08 ^b ± 0.30	8.56 ^d ± 0.33	10.20 ^c ± 0.32
Springiness (mm)	0.92 ^a ± 0.01	0.87 ^b ± 0.01	0.89 ^{ab} ± 0.01	0.89 ^{ab} ± 0.01
Chewiness (N.m)	1022.38 ^a ± 16.60	793.82 ^b ± 10.35	494.16 ^d ± 9.70	640.10 ^c ± 22.53
Cohesiveness (–)	0.75 ^a ± 0.02	0.63 ^d ± 0.01	0.66 ^c ± 0.01	0.69 ^b ± 0.00
Resilience (–)	0.48 ^a ± 0.02	0.35 ^c ± 0.01	0.38 ^{bc} ± 0.01	0.41 ^b ± 0.01

Means in the same line followed by different letters differ from each other according to the Tukey test ($P < 0.05$). F1: rice flour; F2: sorghum flour; F3: teff flour; FO: optimised formulation.

change in the descriptive sensory profile of these products. This finding indicates the possibility of including healthier flours in gluten-free cakes, improving the nutritional quality of processed foods for people with celiac disease or gluten intolerance.

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Data availability statement

Research data are not shared.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. Cakes related to formulations F1, F2, F3 and FO.