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CHEMICAL SCIENCES

Physical, chemical and sensory implications of pequi (*Caryocar brasiliense* Camb.) sweet bread made with flour, pulp and fruit by-product

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Abstract: This study aimed to develop and evaluate bread with the use of pulp and flours of pequi, in partial replacement of water and wheat flour, to develop a bakery product with good technological, nutritional and sensorial qualities. The pequi husk and pulp flours were obtained by means of a thermal pre-treatment, oven drying and standardization of the dry material. Whereas, the bread formulation was defined through the baker's formulation. Besides, the dehydration process caused significant changes ($p<0.05$) in the L* value and chromaticity (C*), mainly of the flours (husk and pequi pulp), such changes are due to non-enzymatic oxidative processes and pigment degradation, especially carotenoids. The effect of the substitution of ingredients (wheat flour and water) by husk and pulp flours and pequi pulp contributed to the increase in lipid, crude fiber, nitrogen-free extract and energy value content. However, the substitution promoted changes in the attributes of color and textural properties, such as increased hardness, chewiness and cohesiveness. Nevertheless, all formulations showed good sensory acceptance and thus, pequi sweet breads can be implemented in school meals for contributing and meeting the nutritional recommendations established by the School Feeding Brazilian Program (PNAE).

Key words: Bakery technology, quality, brazilian fruit, sensory acceptance, school meals.

INTRODUCTION

Brazil has wide biodiversity of natural resources including many fruits species with nutritional, functional and economic potential. The Cerrado is the second largest Brazilian biome accounting for approximately 25% of its territory. Among its native fruit species, is the "pequizeiro" (*Caryocar brasiliense* Camb., *Caryocaraceae* family), with fruits known as pequi (Geöcze et al. 2013, Mendonça et al. 2016, Rodrigues et al. 2015).

The pequi is popularly known as "gold of the Cerrado" and is widely disseminated throughout Brazil. The fruit is covered with a thin peel of gray-green color, the exocarp, that is adhered to the light yellow colored outer mesocarp. Commonly called husk, the exocarp + outer mesocarp set represents about 80% of the weight of the fruit. It involves one to four pyrenes, consisting of the inner mesocarp, the most appreciated portion of the fruit for consumption and the woody endocarp, full of thin and sharp thorns. Inside the fruit is a large fleshy seed (Leão et al. 2017, Rodrigues et al. 2015, Vilas Boas et al. 2012).

Some studies have reported that the constitution of pequi exocarp + external mesocarp is an important source of antioxidants (Roesler et al. 2007), as well as fiber and minerals (Junior et al. 2009) However, despite the technological potential of this by-product, this part of the fruit is discarded (Leão et al. 2018). Besides, several studies have demonstrated and emphasized the nutritional and functional value of the fruit, as it is highly caloric (150 kcal 100 g^{-1} to 308.95 kcal 100 g^{-1}), rich in lipids (27 g 100 g^{-1} to 35 g 100 g^{-1}), total carotenoids (7.25 mg 100 g^{-1} to 14.80 mg 100 g^{-1}), phenolic compounds (60.27 mg EAG 100 g^{-1} to 194.52 mg EAG 100 g^{-1}), vitamin C (50 mg 100 g^{-1} to 105 mg 100 g^{-1}) and minerals, especially iron (1.01 mg 100 g^{-1} to 1.40 mg 100 g^{-1}), zinc (2.81 mg 100 g^{-1} to 3.51 mg 100 g^{-1}), phosphorus (136.62 mg 100 g^{-1} to 294.24 mg 100 g^{-1}) and calcium (51.70 mg 100 g^{-1} to 107.01 mg 100 g^{-1}) (Almeida et al. 2019, Alves et al. 2014, Arruda et al. 2012, Gonçalves et al. 2011, Ribeiro et al. 2012, Rodrigues et al. 2009, 2015)

One way to add value to pequi would be its full use, including its husk, in human food (Leão et al. 2017, Santos et al. 2018). In effect, the whole pequi fruit has technological applicability for the elaboration and insertion of new food products in the market and it can be used in the nutritional and functional enrichment of food products of wide consumption, especially bakery products. It is emphasized that bakery products are caloric products that deliver little more than carbohydrates. Therefore, one of the ways to promote the increase in the consumption of bread and improve its nutritional and functional potential would be the incorporation of these fruits and their by-products in bakery products. This can be done through the partial substitution of some ingredients used in the formulation, to meet nutritional and metabolic needs, especially of school-age children.

The World Food Programme (WFP) supports school feeding initiatives and establishes National School Feeding Programs. In 2019, around 17.3 million schoolchildren received WPF school meals in 59 countries (WFP 2021). In Brazil, the National School Feeding Program (PNAE) is one of the largest and most successful school feeding programs in the world, which aims to provide adequate and healthy food to all students enrolled in basic education in public schools in the country. Created in the mid-1950s, its scope was expanded through Law No. 11.947/2009, which guarantees the State´s obligation to acquire at least 30% of the value and pass on the direct purchase of family farming products (Brazil 2009, Locatelli et al. 2018, Santos et al. 2016, Soares et al. 2017).

Recently, the Brazilian government law project 7.745/2017, which proposes the inclusion of bakery items in school lunches, was approved. It creates an additional percentage of 5% of the resources transferred on the purchase of bread products produced by micro and small local entrepreneurs (Brazil 2018, Schneider et al. 2016). Thus, with the development and insertion of bakery products enriched with fruits of the Cerrado and its by-products, the bakery market stimulates the diversification of production and spreads the consumption of exotic fruits and the valorization of regional foods, with possible nutritional and functional gains (Arruda & Almeida 2015, Monego et al. 2013).

Given the above, the present work aimed to develop breads with the use of pulp and flours of pequi, in partial replacement of water and wheat flour, looking for a bakery product with good technological, nutritional and sensory qualities.

MATERIALS AND METHODS

Obtaining the raw material

The pequi was collected and purchased in the city of Montes Claros – Minas Gerais and transported to the Laboratory of Fruits and Vegetables Postharvest of the Federal University of Lavras, Lavras – Minas Gerais, Brazil, where it was used to obtain flour from the husk (exocarp + external mesocarp), pulp flour (internal mesocarp) and pequi pulp in the preparation of sweet breads. The fruits were selected and subjected to pre-washing in running water, for removal of coarser dirt. They were then sanitized in a solution containing sodium hypochlorite at 100 ppm for 15 minutes and then halved. The husk was separated from the pyrenes, which were placed in polyethylene plastic bags and stored at -18 °C in a freezer for one year, until the pulp was processed, and the flour was prepared.

Obtaining flour and pulp

To obtain the pequi husk flour, steam bleaching was performed for 12 minutes, and then the blanched husks were placed in forms and over-dried at 65 °C for 24 hours in an oven. In the case of obtaining the pequi and its flour, steam bleaching was also performed in the pyrenes for 12 minutes and subsequent pulping, using a household grater to separate only the inner mesocarp, called pulp. Subsequently, to obtain the flours, the pulp was submitted to over-drying at 65 °C for 24 hours in an oven. It was then necessary to grind the dry material in a knife mill, sieve it using a No. 9 mesh sieve with 2.2 mm and homogenize the material to obtain a uniformly granular product. The flours obtained were packed in polyethylene plastic films, vacuum-sealed and kept in a dry and airy place until the bread was prepared.

Bread processing

The control breads were made from the following basic formulation (percentage of backer): wheat flour (100%), water (45%), crystal sugar (15%), eggs (15%), milk powder (6%), soybean oil (5%), yeast (2.5%) and salt (2%). The percentage of the ingredients was calculated based on the total of the main ingredient, in the specific case, wheat flour. The enriched bread presented the same formulation, except for the partial replacement of wheat flour by husk flours and pequi pulp flours and water by pequi pulp. The direct method of fermentation was used for the bread formulation, in which all dry ingredients are mixed: wheat flour, crystal sugar, eggs, yeast, and milk powder. Once homogenized, the wet ingredients were added: eggs, water and oil. Finally, salt was added until the development of the gluten or “veil point” network. The batter was mixed in Wallita®, with five speeds and 250W of power, mixer at top speed for five minutes. Subsequently, the dough was weighed, divided, rounded and shaped in the G.Painz® bread machine and taken to the Klimaquip® fermentation chamber (30 °C and ± 90% RH) for one hour and thirty minutes. Soon after, the fermented dough was baked in a Practical Techicook® semi-industrial electric oven at 150°C for 20 minutes. The bread was then cooled to room temperature and sliced. Right after cooling, slices of the breads were frozen, using liquid nitrogen and packed in polyethylene bags and finally, stored at -18 °C in a freezer, for later analysis. After 24 hours of cooling, the physical and chemical analyses were performed, while the sensory analyses were performed on the same day as bread preparation.

Analysis

Color

Measurements of bread crust and crumb color were performed using the Konica Minolta CR-400 colorimeter (Minolta, São Paulo, Brazil) calibrated according to the CIE system with measurement of L*, C* and °hue (D_{65} illuminant). The results of each color variables were obtained from the average of five bread replicates for each repetition.

Texture profile (TPA)

TPA was performed according to Garzón et al. (2017) and Jekle et al. (2018) using the texture analyzer (model TA – XT2i, Stable Micro Systems, United Kingdom) with a 36 mm cylindrical probe programmed for two cycles. Measurements were performed under the following conditions: pre and posttest velocity of 5 mm s^{-1}; 2 mm s^{-1} test speed; compression distance 5.0 mm; an interval between cycles of 10 second. For the test, two overlapping slices of 1 cm each were placed. The samples were compressed to about 50% of their original height. The variables: hardness, elasticity, cohesiveness and chewiness were evaluated from the average of five bread replicates for each repetition.

Proximal composition

Moisture (method No. 967.08), lipids (methods No. 2003.06), protein (method No. 988.05), ash (method No. 942.05), and crude fiber (method 958.06) were performed according to the methodology described by the Association of Official Analytical Chemists (2012) and the nitrogen-free extract was obtained by subtracting the values obtained from previous analysis of 100 g of sample, in the whole matter. The results were expressed as a percentage of fresh matter (g 100 g^{-1}). The total energy value was estimated using the Atwater conversion values, described by Zou et al. (2007) and the result expressed in kilocalories (kcal 100 g^{-1}).

Sensory

The sensory analysis was performed with the approval of the Research Ethics Committee of the Federal University of Lavras, Lavras – Minas Gerais, Brazil, under process No. 2.227.875, held at the municipal school “Álvaro Botelho” located in Lavras – Minas Gerais, Brazil, with the participation of ninety tasters, of both sexes, aged six to ten years. The bread samples were served in balanced and monadic order, coded in three digits of random numbers, divided into two separate sessions, with four samples offered for each session. The tasters evaluated, through an affective test, the sensory acceptance of the product, using a five-point facial scale (5 = “I loved it” to 1 = “I hated it”), according to Stone et al. (2012).

Statistic

The statistical analysis of the physical and chemical analysis were performed using the Statistical Analysis of Variance System – SISVAR version 5.4 (Ferreira 2011). The data were subjected to analyses of variance and averages compared by the Scott-Knott test with a significant level at 5% probability. The statistical analysis to estimate the acceptability index between the different samples was performed by the statistical program R version 3.6.3 (TEAM 2020), using the ordinal and emmeans packages. With the data of sensory acceptance, multivariate statistical analysis was performed using internal mapping. As well as, Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were carried out to understand the similarity between the physical and chemical analyzes carried out on the different sweet bread formulations, using the SENSOMAKER version 1.91 (Pinheiro et al. 2013). To understand the composition of each Principal Component (PCs) concerning physical and chemical variables, loadings were calculated using the PCA function of the MVar.pt package of the statistical program R version 3.6.3 (TEAM 2020).

Experimental design

The selection of different pequi flour and pulp substitution levels were obtained from an experimental design previously performed. For the experimental design (Figure 1), a Completely

Figure 1. Cross sections of bread made from the partial replacement of wheat flour by pequi pulp and husk flours and water by pequi pulp. Treatments, from left to right: T_1: standard formulation; T_2: 2.5% PHF; T_3: 20% PPF; T_4: 2.5% PHF + 20% PPF; T_5: 35% PP; T_6: 2.5% PHF + 35% PP; T_7: 20% PPF + 35% PP; T_8: 2.5% PHF + 20% PPF + 35% PP. Abbreviations of the terms of each formulation (T_1 - T_8): PHF: pequi husk flour; PPF: pequi pulp flour and PP: pequi pulp.

Randomized Design (CRD) was used, in a 2 x 2 x 2 factorial design, with 2 levels of the 'pequi husk flour', partially replacing the wheat flour (0% and 2.5%), 2 levels of the 'pequi pulp flour' factor, partially replacing wheat flour (0% and 20%) and 2 levels of the 'pequi pulp' factor, partially replacing water (0% and 35%), with three repetitions and the experimental portion consisted of 4 bread with approximately 70 g each.

RESULTS AND DISCUSSION

Physical and chemical characteristics of pulp and flours of husk and pequi pulp

The variables related to color, proximal composition and energy value of pulp and flours of husk and pequi pulp are presented in Table II.

Significant differences ($p<0.05$) were found in the color-related variables among the study target raw materials used in the preparation of the bread (Table II). Based on the L* value, it appears that the pequi husk flour has a darker shade than the other raw materials and that the transformation of the pequi pulp into flour promoted it is darkening. This darkening is probably due to non-enzymatic oxidation processes that result in the formation of dark compounds in the husk and pulp flours from the Maillard reaction and ascorbic oxidative process (Hoffmann et al. 2017, Jaeger et al. 2010), resulting from the drying process (temperature above 60°C).

The chromaticity variable (C*) indicates color saturation, thus, the higher the results, the more attractive certain foods are considered (Gonçalves et al. 2011, Vilas Boas et al. 2012). The pequi pulp presented a more intense color (56.03 ± 0.49) concerning the pulp flour (42.87 ± 0.84) (Table II). Thus, the reduction in pulp flour chromaticity suggests a decrease in color intensity, probably due to the dehydration process, which caused the degradation of carotenoid pigments. Comparing the flours, the pulp flour has a higher C* than the husk flour, suggesting a more attractive product from the point of view of tone. There was also a significant reduction ($p<0.05$) of °hue between pequi pulp and pulp flour, indicating changes in the color hue from pequi pulp to orange in pequi pulp flour. The value found is similar to that reported by Gonçalves et al. (2011), corresponding to the angle of 71.65. The pulp and husk flour did not differ in terms of °hue.

The proximate composition and energy value also varied significantly ($p<0.05$) as a function of the target raw materials of this study (Table II). The husk flour presented higher moisture content than the pequi pulp flour. According to the current legislation (Brazil 2005), the maximum moisture content of flour and meal corresponds to 15%. Thus, fruit flours used as substitutes are within the standard required by the legislation (Table II). The low moisture content contributes to the better conservation of the product, as it reduces the water available for microorganism proliferation and chemical reactions (Soquetta et al. 2016). The moisture content observed in the pulp is higher than that reported in studies by Alves et al. (2014) of 54.78 g 100 g^{-1} and by Arruda et al. (2012), corresponding to 41.50 g 100 g^{-1}.

The drying process used to transform pequi pulp into flour concentrated the centesimal components, as a function of moisture reduction ($p<0.05$, Table II). Pequi pulp flour presented a higher lipid and protein contents and lower ash, fiber and glycid contents than pequi husk flour (Table II). The lipid contents observed in pequi husk flour are similar to those reported by Siqueira et al. (2013) when working with the same product. Pequi pulp has a higher protein content than most fruits, although fruits are usually considered sources of carbohydrates and other centesimal constituents, except for protein content (Soares et al. 2017). While the protein content of pequi husk flour was lower than that of wheat flour and pequi pulp flour had a protein content similar to that of flour, such as from corn and rice (Dors et al. 2006, Giacomelli et al. 2012). The average protein levels observed in pequi husk and pulp flours are higher than those reported in the literature, which records values of up to 3.48 g 100 g^{-1} for pequi husk flour and 1.03 g 100 g^{-1} to 3.73 g 100 g^{-1} for pequi pulp flour (Alves et al. 2014, Berto et al. 2015, Monteiro et al. 2015, Siqueira et al. 2013).

The ash content observed in pequi husk flour is similar to that found by Siqueira et al. (2013), which corresponds to 2.09 g 100 g^{-1}, while observed in pequi pulp, is within the value reported by Alves et al. (2014), which corresponds to 0.67 g 100 g^{-1}.

The crude fiber content observed in pequi husk flour is similar to that reported by Couto (2007) and in their studies, the average value for crude fiber corresponds to 11.74 g 100 g^{-1} (whole matter). Leão et al. (2017), when evaluating the profile of monosaccharides present in pequi husk flour, revealed the presence of a large number of pectin polysaccharides (± 56%), which corresponds to high content, consisting mainly of soluble fibers.

Regarding the glycidic content and energy value among the target raw materials of this study, the pequi husk flour presented the highest content related to the nitrogen-free extract (64.60 g 100 g^{-1}), while, the pulp flour has the highest energy value (617.52 kcal 100 g^{-1}) and the pulp has the lowest content for both centesimal composition variables (Table II). The nitrogen-free extract result for pequi husk flour is lower than that reported by Couto (2007), when studying the use of pequi husk flour in the preparation of loaf bread, a value that corresponds to 72.96 g 100 g^{-1} (whole matter). While the high caloric value of pequi pulp flour is mainly due to the high lipid content found and the low content relative to the glycemic fraction in the pulp is directly related to the high moisture content found.

In general, the pequi pulp and flours of its husk and pulp have nutritional and functional components that allow its applicability in the preparation and enrichment of bread.

Physical and chemical characteristics of bread

The variables related to the physical and chemical characteristics of the sweet breads made with pequi flours and pulp are presented in Table III.

Regarding the bread crust, L* value, the formulations T_3 (20% pequi pulp flour), T_4 (2.5% pequi husk flour + 20% pequi pulp flour) and T_8 (2.5% pequi husk flour + 20% pequi pulp flour + 35% pequi pulp) did not differ statistically from each other and presented a darker shade compared to control bread (T_1) and other treatments ($p<0.05$) (Table III). These treatments (T_3, T_4 and T_8) have the partial substitution of wheat flour by 20% pequi pulp flour and the darker coloration observed in the fruit flour in common. Furthermore, the protein content (Table I) and sugars contained in this raw material studied, may have favored the darkening of the hue in the crust indicating, a more pigmented region compared to the other treatments. According to Ahrneá et al. (2007), this change in bread crust color can be attributed to non-enzymatic brownings, such as seen in the Maillard reaction and caramelization reactions. Thus, the pigments formed in the crust are influenced by the quality and quantity of precursors, such as reducing sugars and proteins from flour and pulp used as ingredients, leading to the formation of polymerized proteins and brown pigments (Shibao & Bastos 2011, Jusoh et al. 2009, Martins et al. 2001).

Regarding the chromaticity (C*) in the bread crust, it was observed that the values ranged from 34.92 (T_2: 2.5% pequi pulp flour) to 41.46 (T_7: 20% pequi pulp flour + 35% pequi pulp), classifying them statistically ($p<0.05$) as follows, in ascending order: T_1, T_2, T_3 < T_4, T_5, T_6, T_8 < T_7 and treatment T_7 (20% pequi pulp flour + 35% pequi pulp) presented the highest chromaticity (Table III). The result is consistent with the higher chromaticity values for pulp flour and pequi pulp concerning pequi husk flour (Table II). The authors Sant'anna et al. (2013) and Mau et al. (2019) describe that chromaticity provides information on the vividness of a color, so the higher the results found, the more attractive the food becomes.

In the case of bread crust °hue, the treatments are statistically classified ($p<0.05$) in the following ascending order: T_1, T_2, T_3, T_4 < T_5, T_6, T_7 and T_8 (Table III). The hue progression occurred in the crust, since the treatment T_5 (35% pequi pulp), T_6 (2.5% pequi husk flour + 35% pequi pulp), T_7 (20% pequi pulp flour + 35% pequi pulp) and T_8 (2.5% pequi husk flour

Table I. Sweet bread formulations based to partial replacement of wheat flour with pequi husk and pulp flours and water with pequi pulp.

Ingredients	Formulation (g)							
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
Wheat flour	300	292.5	240	232.5	300	292.5	240	232.5
Water	135	135	135	135	87.75	87.75	87.75	87.75
Milk powder	18	18	18	18	18	18	18	18
Crystal sugar	45	45	45	45	45	45	45	45
Yeast	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Eggs	45	45	45	45	45	45	45	45
Soybean oil	15	15	15	15	15	15	15	15
Salt	6	6	6	6	6	6	6	6
Pequi husk flour	0	7.5	0	7.5	0	7.5	0	7.5
Pequi pulp flour	0	0	60	60	0	0	60	60
Pequi pulp	0	0	0	0	47.25	47.25	47.25	47.25

Notes: T_1: standard formulation; T_2: 2.5% PHF; T_3: 20% PPF; T_4: 2.5% PHF + 20% PPF; T_5: 35% PP; T_6: 2.5% PHF + 35% PP; T_7: 20% PPF + 35% PP; T_8: 2.5% PHF + 20% PPF + 35% PP. Abbreviations: PHF: pequi husk flour; PPF: pequi pulp flour and PP: pequi pulp.

+ 20% pequi pulp flour + 35% pequi pulp) have, in common, the partial replacement of part of the water by 35% pequi pulp. This raw material studied stands out significantly ($p<0.05$) from the others for presenting the highest °hue value (Table II). Thus, the bread crust generally ranges from reddish-orange to yellow-orange shades.

Regarding the crumb color, referring to the L* value, the formulations T_4 (2.5% pequi husk flour + 20% pequi pulp flour) and T_8 (2.5% pequi husk flour + 20% pequi pulp flour + 35% pequi pulp) did not differ statistically and were darker, whereas the standard formulation and T_5 (35% pequi pulp) were similar to each other and were lighter ($p<0.05$) (Table III). Thus, the color of the crumb is strongly influenced by the use of flours and pulp, because of the predominant color and characteristic of these ingredients used in the manufacture of bread. According to Dhen et al. (2018), since the temperature during baking does not exceed 150 °C inside the bread, it can be predicted that may modify the original color of the raw materials studied and used as ingredients.

Regarding the chromaticity (C*) of the bread crumbs, the T_7 treatment (20% pequi pulp flour + 35% pequi pulp) differed statistically ($p<0.05$) from the standard formulation and the other treatments presenting the highest chromaticity value (Table III), the same condition observed regarding the chromaticity in the bread crust with this formulation. This result is consistent with the higher average chromaticity value referring mainly to pequi pulp (Table II).

From the °hue results of the bread crumbs, color progressions were observed ranging from 68.93 (T_2: 2.5% pequi husk flour) to 81.69 (T_5: 35% pequi pulp) (Table III). Regarding the color of the crumb, only the T_5 treatment (35% pequi pulp) was statistically different from the others ($p<0.05$) with a predominantly yellowish coloration, in line with the higher color angle observed in the pequi pulp (Table II).

In this study the effect of partial replacement of wheat flour by pequi pulp and husk flours and water by pequi pulp generally led to significant changes ($p<0.05$) in the textural properties of the sweet breads, especially the replacements

Table II. Physical and chemical characteristics of the quality of the raw materials used in bread preparation.

Quality features	Pequi husk flour	Pequi pulp flour	Pequi pulp
Coloring			
L*	56.23 ± 0.21 c	57.27 ± 0.20 b	59.67 ± 0.75 a
C*	21.73 ± 0.15 c	42.87 ± 0.84 b	56. 03 ± 0.49 a
°hue	66.07 ± 0.23 b	65.80 ± 0.26 b	74.27 ± 0.15 a
Proximal composition			
Moisture	14.76 ± 0.02 b	2.42 ± 0.12 c	63.85 ± 0.01 a
Lipids content	1.32 ± 0.17 c	55.55 ± 0.41 a	23.79 ± 2.03 b
Protein	4.27 ± 0.88 b	6.03 ± 0.20 a	3.56 ± 0.37 b
Ash	2.19 ± 0.02 a	1.36 ± 0.16 b	0.62 ± 0.04 c
Crude fiber	12.88 ± 0.01 a	11.27 ± 0.15 b	5.21 ± 0.07 c
Nitrogen-free extract	64.60 ± 1.05 a	23.36 ± 0.21 b	2.96 ± 1.92 c
Total energy value	287.31 ± 0.82 b	617.52 ± 3.71 a	240.21 ± 10.04 c

Notes: Values are means ± standard deviation (n=3); Proximal composition calculated in the whole matter and expressed in g 100 g^{-1} and kcal 100 g^{-1}. Means followed by the same letters do not differ from each other by the Scott-Knott test at 5% probability.

referring to pequi pulp, leading to decrease of elasticity and increase in hardness, chewiness and cohesiveness values. A similar result was reported by Torbica et al. (2019), from studies carried out through the substitution of food by-products used in the enrichment of whole-grain bread.

Bread hardness, chewiness and cohesiveness increased in treatments T_5 (35% pequi pulp), T_6 (2.5% pequi husk flour + 35% pequi pulp), T_7 (20% pequi pulp flour + 35% pequi pulp) and T_8 (2.5% pequi husk flour + 20% pequi pulp flour + 35% pequi pulp), from the increment of 35% pequi pulp in partial replacement with water (Table II). Thus, the high levels of fiber present in the raw materials studied and used in the substitution of ingredients (Table I), as well as the reduction of part of the water used as an ingredient, made the crumb firmer due to the increase in hardness, with lower crumbling tendency due to high cohesiveness but requiring higher chewiness energy, as already reviewed by Ktenioudaki & Gallagher (2012).

Using the Principal Component Analysis (PCA) (Figure 2a), it is possible to observe that the first Principal Component (PC_1) describes 99.65% of the total variance, as well as, the variables hardness and chewiness are positively correlated and indicate a strong loading effect on that component. Regarding the second

Table III. Physical and chemical characteristics of bread quality.

Quality features	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
Bread crust coloring								
L*	46.03 ^{a}	46.93 ^{a}	41.00 ^{b}	43.09 ^{b}	49.23 ^{a}	47.24 ^{a}	45.37 ^{a}	42.96 ^{b}
C*	35.50 ^{c}	34.92 ^{c}	35.66 ^{c}	38.46 ^{b}	37.81 ^{b}	37.59 ^{b}	41.46 ^{a}	38.57 ^{b}
ºhue	51.77 ^{b}	53.03 ^{b}	50.48 ^{b}	53.28 ^{b}	58.07 ^{a}	57.05 ^{a}	56.73 ^{a}	54.89 ^{a}
Bread crumb coloring								
L*	72.75 ^{a}	62.05 ^{c}	60.83 ^{c}	57.22 ^{e}	71.77 ^{a}	63.97 ^{b}	59.73 ^{d}	57.34 ^{e}
C*	20.63 ^{g}	22.18 ^{g}	52.37 ^{c}	49.79 ^{d}	39.27 ^{e}	34.48 ^{f}	56.59 ^{a}	54.93 ^{b}
° hue	78.80 ^{b}	68.93 ^{d}	78.93 ^{b}	75.53 ^{c}	81.69 ^{a}	76.06 ^{c}	77.29 ^{c}	76.23 ^{c}
Texture profile								
Hardness	2.561.85 ^{b}	2.593.70 ^{b}	2.012.49 ^{b}	2.167.44 ^{b}	3.502.31 ^{a}	3.194.38 ^{a}	2.730.25 ^{a}	3.169.52 ^{a}
Elasticity	0.95 ^{a}	0.94 ^{a}	0.90 ^{b}	0.90 ^{b}	0.94 ^{a}	0.92 ^{b}	0.88 ^{b}	0.89 ^{b}
Cohesiveness	0.65 ^{b}	0.65 ^{b}	0.64 ^{b}	0.66 ^{b}	0.67 ^{a}	0.69 ^{a}	0.67 ^{a}	0.68 ^{a}
Chewiness	1.584.11 ^{b}	1.571.23 ^{b}	1.162.69 ^{c}	1.273.37 ^{c}	2.216.12 ^{a}	2.026.03 ^{a}	1.610.16 ^{a}	1.898.69 ^{a}
Proximal composition								
Moisture	29.98 ^{a}	30.02 ^{a}	30.05 ^{a}	30.09 ^{a}	28.20 ^{c}	28.96 ^{b}	27.80 ^{c}	27.45 ^{c}
Lipids content	1.43 ^{d}	1.89 ^{d}	10.61 ^{b}	10.42 ^{b}	3.32 ^{c}	3.62 ^{c}	12.37 ^{a}	12.70 ^{a}
Protein	9.71 ^{a}	8.07 ^{a}	7.10 ^{a}	7.40 ^{a}	8.21 ^{a}	7.91 ^{a}	7.45 ^{a}	8.23 ^{a}
Ash	1.95 ^{a}	1.52 ^{a}	1.62 ^{a}	1.61 ^{a}	1.52 ^{a}	1.91 ^{a}	1.73 ^{a}	1.65 ^{a}
Crude fiber	0.45 ^{e}	0.61 ^{d}	0.76 ^{c}	1.15 ^{b}	0.59 ^{d}	0.78 ^{c}	1.14 ^{b}	1.69 ^{a}
Nitrogen-free extract	57.65 ^{a}	58.77 ^{a}	50.07 ^{b}	50.30 ^{b}	59.21 ^{a}	57.38 ^{a}	50.80 ^{b}	49.64 ^{b}
Total energy value	280.32 ^{d}	282.85 ^{d}	327.06 ^{b}	326.58 ^{b}	301.51 ^{c}	295.77 ^{c}	344.78 ^{a}	347.29 ^{a}

Notes: Values are means ± standard deviation (n=3); Proximal composition calculated in whole matter and expressed in g 100 g^{-1} and kcal 100 g^{-1}. Means followed by the same letters do not differ from each other by Scott-Knott test at 5% probability. Subtitle: T_1: standard formulation; T_2: 2.5% PHF; T_3: 20% PPF; T_4: 2.5% PHF + 20% PPF; T_5: 35% PP; T_6: 2.5% PHF + 35% PP; T_7: 20% PPF + 35% PP; T_8: 2.5% PHF + 20% PPF + 35% PP. Abbreviations of the terms of each formulation (T_1 - T_8): PHF: pequi husk flour; PPF: pequi pulp flour and PP: pequi pulp.

Principal Component (PC_2), despite describing only 0.32% of the total variance, it is observed that the variables C* crumb and hardness are negatively correlated and indicate a strong loading effect on this component (Figure 2c). Thus, considering PC_1 and hierarchical cluster analysis (HCA) it is possible to observe the formation of three distinct groups (Figure 2b). The first group is represented by the treatments 1, 2 and 7; the second group by treatments 3 and 4 and the third group by treatments 5, 6 and 8, with the first two groups (T_1, T_2, T_3, T_4, and T_7) having in common, greater brightness (L*), chromaticity (C*), tint angle (ºhue), greater elasticity and cohesiveness, compared to the third group (T_5, T_6 and T_8), which are close to other physical variables, especially the hardness and chewiness of the crumb (Figure 2).

According to current Brazilian legislation (Brazil 2005), the maximum moisture content for bread should be 38%. Thus, the moisture levels for the different sweet bread formulations do not exceed the maximum standard required by the legislation. As shown in Table II, the treatments T_5 (35% pequi pulp), T_6 (2.5% pequi husk flour + 35% pequi pulp), T_7 (20% pequi pulp flour + 35% pequi pulp) and T_8 (2.5% pequi husk flour + 20% pequi pulp flour + 35% pequi pulp), all with 35% water substitution by pequi pulp, had the lowest moisture results, differing significantly ($p<0.05$) from the standard formulation (T_1) and other treatments. The reduction in moisture content is mainly due to the reduction in the amount of water used in the formulations, due to its partial replacement by pequi pulp.

Regarding the lipid contents, the treatments that had the replacement of wheat flour by pequi pulp flour (treatments T_3, T_4, T_7, and T_8) presented the highest averages, when compared to the other treatments, with the replacement of water by pequi pulp (treatments T_7 and T_8), the highest averages were determined ($p<0.05$, Table III). This significant increase refers mainly to the high levels of lipid content found in pequi flour and pequi pulp (Table II). However, treatments T_5 (35% pequi pulp), T_6 (2.5% pequi husk flour + 35% pequi pulp) showed significantly higher lipid content ($p<0.05$) compared to the

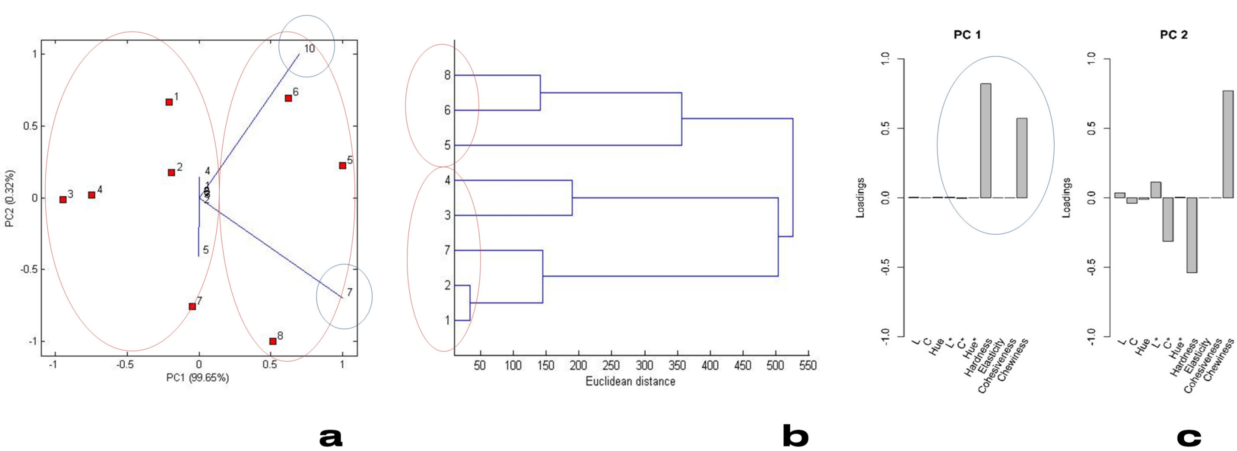

Figure 2. **(a) Analysis of the main components (PCA) between the physical analyses performed on sweet breads; (b) Dendogram of the different variables analyzed between the physical parameters of color and texture profile [L*, C* and ºhue of the crust; L*, C* and ºhue; hardness, elasticity, cohesiveness and chewiness] of sweet breads made with pequi husk flour, pequi pulp flour and pequi pulp and (c) Loadings of each main component (PCs) in relation to physical variables. Subtitle: (.) 1: standard formulation; 2: 2.5% PHF; 3: 20% PPF; 4: 2.5% PHF + 20% PPF; 5: 35% PP; 6: 2.5% PHF + 35% PP; 7: 20% PPF + 35% PP; 8: 2.5% PHF + 20% PPF + 35% PP. Abbreviations of the terms of each formulation (1 - 8): PHF: pequi husk flour; PPF: pequi pulp flour and PP: pequi pulp. (.) 1: L* crust; 2: C* crust; 3: ºhue crust; 4: L* crumb; 5: C* crumb; 6: ºhue crumb; 7: hardness; 8: elasticity; 9: cohesiveness and 10: chewiness.**

standard formulation (T_1) and treatment T_2 (2.5% pequi husk flour), since pequi pulp also has a significantly higher lipid content ($p<0.05$) compared to pequi husk flour (Table II).

Table II indicates that the substitution of pequi husk and pulp flours, and pequi pulp had no significant influence ($p>0.05$) on the protein content of bread. The non-significance is directly related to the low percentage of protein present in the studied raw materials, since fruits, in general, are not vehicles of this nutritional constituent. The ash content observed for pequi husk flour and pequi pulp flour, although following the values observed and reported by different studies, such as Siqueira et al. (2013) and Alves et al. (2014), also did not exert significant influence ($p>0.05$) on the fixed mineral content of the different sweet bread formulations (Table III).

Regarding crude fiber, differences between treatments were observed, statistically classifying them ($p<0.05$) in the following ascending order: $T_1 < T_2, T_5 < T_3, T_6 < T_4, T_7 < T_8$ (Table III). A for T_8 treatment (2.5% pequi husk flour + 20% pequi pulp flour + 35% pequi pulp) showed a significant contribution ($p<0.05$) in fiber increment, since, pequi husk and pulp flours contribute significantly with a higher fiber content ($p<0.05$) compared to the pulp (Table II).

Sweet breads related to treatments T_3 (20% pequi pulp flour), T_4 (2.5% pequi husk flour + 20% pequi pulp flour), T_7 (20% pequi pulp flour + 35% pequi pulp), and T_8 (2.5% pequi husk flour + 20% pequi pulp flour + 35% pequi pulp) have, in common, the presence the pequi pulp flour in their formulation and presented the lowest levels of nitrogen-free extract compared to the control formulation (T_1) and other treatments that did not differ from each other (Table III). The contribution of the reduction in the glycidic fraction of these treatments is mainly due to the proximal constitution present in the pequi pulp flour, since it presents a lower glycidic fraction (23.36 g 100 g^{-1}) compared to the pequi husk flour and contributes significantly with a higher fiber content (11.27 g 100 g^{-1}) compared to the pulp (Table II). Thus, the reduction in the glycidic content of bread is replaced by sugars and fiber from fruit flour.

By analyzing the main components (Figure 3a), the first principal component (PC_1) describes 99.31% of the total variation between the proximal components of the different formulations of pequi sweet breads, however, it appears that only the content of lipids and the energy value has a positive correlation and is highly loaded in this component. Besides, although the second principal component (PC_2) explains only 0.61% of the total variation, it is observed that the moisture and lipid content have a positive load, while the non-nitrogen extract and the energy value have a negative load (Figure 3c). Thus, considering the PC_1 and the hierarchical analysis of clusters, it is possible to observe the formation of two groups and two distinct subgroups, among them (Figure 3b). Thus, the first group is represented by treatments T_3, T_4, T_7, and T_8, with the formation of two subgroups, the first through treatments T_3 and T_4 - they have in common, high moisture content and lipid content - and the second, represented by treatments T_7 and T_8 - they also have in common a high lipid content and caloric value. The second group is formed by treatments T_1, T_2, T_5, and T_6, divided into two subgroups. The first formed by treatments T_1 and T_2 - have high moisture content in common - while the second group is formed by treatments T_5 and T_6 - have elevated carbohydrate content. It is observed that the levels of protein, ash and fiber are equidistant between both groups formed (Figure 3).

According to the guidelines National School Feeding Program (PNAE) (Brazil 2014, França et al. 2018), school meals must meet at least

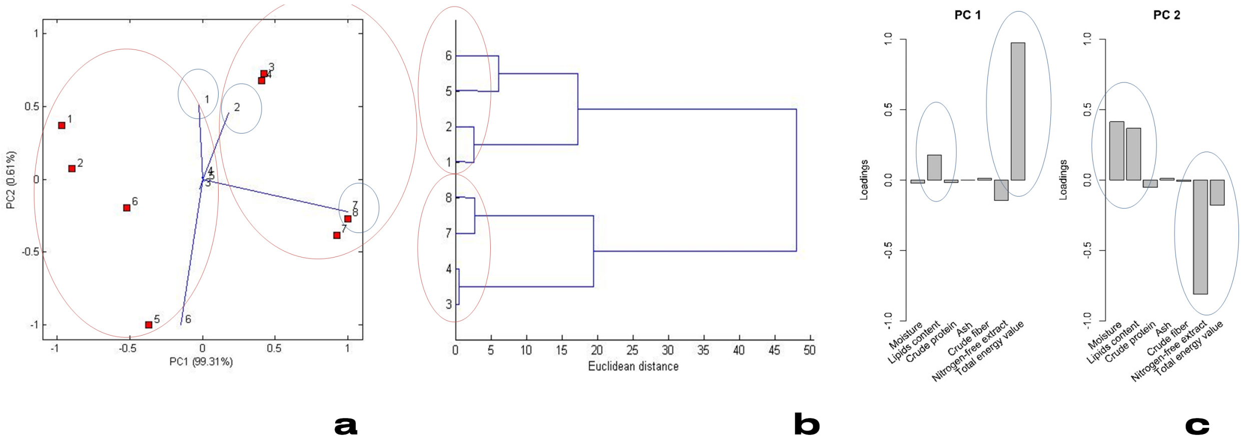

Figure 3. (a) Analysis of the main components (PCA) between proximal analyses performed on sweet breads; (b) Dendogram of the different variables analyzed between the chemical parameters [moisture, lipids, proteins, ash, fiber, glycidic fraction and energy value] of the breads sweets made with pequi husk flour, pequi pulp flour and pequi pulp and (c) Loadings of each main component (PCs) in relation to proximal composition variables. Subtitle: (·) 1: standard formulation; 2: 2.5% PHF; 3: 20% PPF; 4: 2.5% PHF + 20% PPF; 5: 35% PP; 6: 2.5% PHF + 35% PP; 7: 20% PPF + 35% PP; 8: 2.5% PHF + 20% PPF + 35% PP. Abbreviations of the terms of each formulation (1 - 8): PHF: pequi husk flour; PPF: pequi pulp flour and PP: pequi pulp. (·) 1: Moisture; 2: Lipids; 3: Crude protein; 4: Fixed mineral residue (ash); 5: Crude fiber; 6: Non-nitrogen extract (glycidic fraction); 7: Energy value.

20% of the nutritional needs of students aged six to ten years, that is, provide a minimum recommendation of macronutrients. Among these recommendations, a meal should provide 7.50 g 100 g^{-1} lipids; 9.40 g 100 g^{-1} protein; 48.80 g 100 g^{-1} carbohydrate and caloric value of 300 kcal 100 g^{-1} (França et al. 2018).

Considering a portion of 50 g of sweet bread, offered as part of a meal, the treatments with the highest substitution levels and which have in common the presence of pequi pulp flour in their formulation, for example: T_3 (20% pequi pulp flour), T_4 (2.5% pequi husk flour + 20% pequi pulp flour), T_7 (20% pequi pulp flour and 35% pequi pulp), and T_8 (2.5% pequi husk flour + 20% pequi pulp flour + 35% pequi pulp), meet a range ranging from 71 to 84% of the established recommendations regarding lipid content, and provide 54 to 57% in energy content, based on a meal of 100 g. As for protein content, all formulations meet a range of 38% to 48% of the recommendations established by the program. Thus, all formulations may be offered as part of a meal and may be supplemented with other foods to meet the minimum requirements of the National School Feeding Program (PNAE).

Sensory evaluation of bread

The averages of the assigned scores, despite the sensory variables, ranged from 4.23 to 4.62, indicating a range of acceptance, in hedonic terms between “liked” and “loved”. Among the 90 children interviewed, there as a predominance of children enrolled in the 1st and 2nd grades (34.44%), followed by those enrolled in the 3rd grade (25.55%), 5th grade (23.33%) and 4th grade of elementary school (16.66%).

The bread that presented, in common, the substitution of 20% wheat flour by pequi pulp flour, combined or not with the replacement of pequi husk flour and water by pequi pulp (T_3, T_4, T_7, and T_8), did not differ statistically from each other and received the lowest sensory acceptance scores ($p<0.05$) when compared to standard formulation and treatments combined or not with husk flour and/or pequi pulp (T_1, T_2, T_5, and T_6). It is emphasized that all enriched bread, regardless of the formulation, had a sensory acceptance score higher than or equal to the control (T_1), as shown in Figure 4a.

Referring to Figure 4b, both main components (PC_1 and PC_2) explain 42.82% of the variance between samples, regarding acceptance. The spatial separation of the bread samples suggests that the tasters gave different scores for the samples and the lower scores are due to the treatment T_3, T_4, T_7, and T_8, more distant from the vectors, represented by the tasters, thus confirming the analysis of variance and the acceptability index (Table IV). Thus, it can be inferred that all formulations of pequi bread were sensorially well accepted and therefore, can be implemented in school meals, especially the formulation with pequi husk flour and pequi pulp (T_6) which obtained the highest percentage of acceptance (Table IV). These results are following the PNAE guidelines in which the level of acceptance, by the beneficiaries, of a new product must be higher than 85% (Muniz & Carvalho 2007).

CONCLUSION

The combined substitution (T_4, T_6, T_7 and T_8) and substitutions performed alone (T_3 and T_5) between pulp flour and pequi pulp promoted darker shades and with yellow-orange tones in bread crust. In the crumb, the effect of combined substitution (T_4 and T_8) between the highest levels of pulp flour and pequi pulp culminated in a darker hue, while the isolated effect of pulp substitution (T_5) promoted predominantly high yellowish tones. The increase in the combined substitution (T_6, T_7 and T_8) and isolated (T_5) substitution level, referring to pequi pulp, resulted in changes in textural properties, mainly in the decrease of elasticity and in the increase of hardness, chewiness and cohesiveness. It is noteworthy that, by

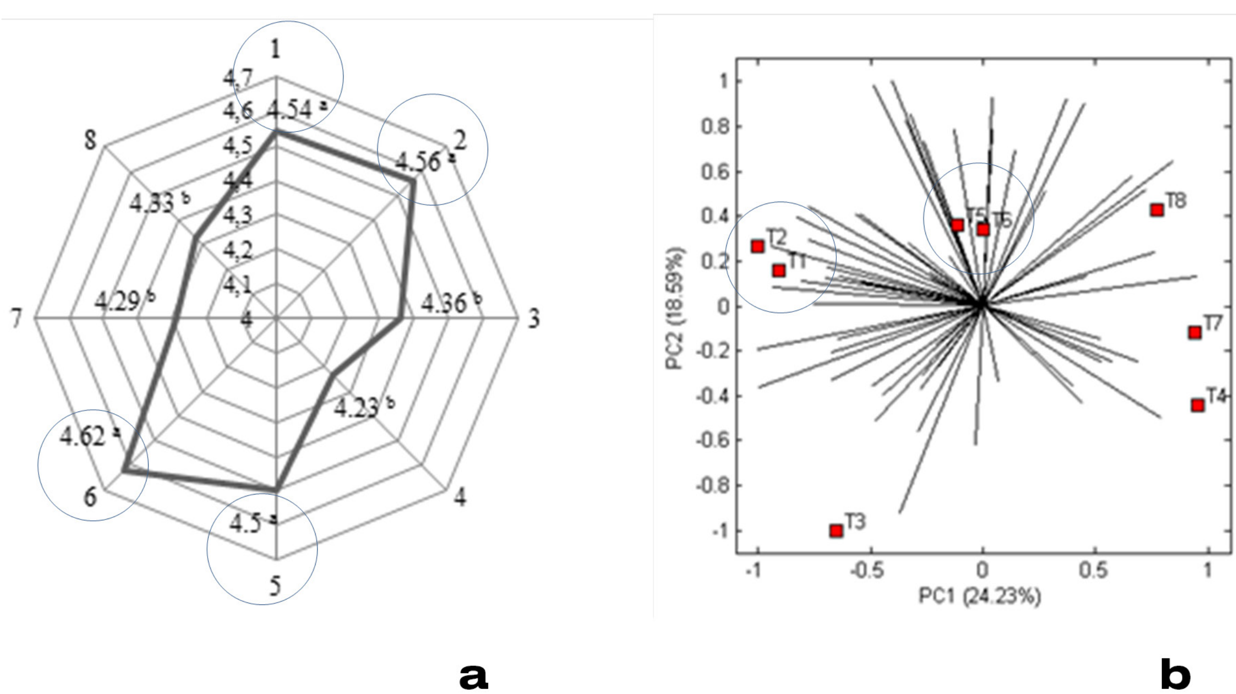

Figure 4. **(a) Radar graph of hedonic quality characteristics of bread made from the partial replacement of wheat flour by pequi pulp and husk flours and water by pequi pulp. (b) Preferred two-way internal map acceptance of pequi sweet bread. Consumers are represented by vectors and treatments by squares. The means (n = 90) followed by the same letters do not differ from each other by the Scott-Knott test at 5% probability.**

Table IV. **Acceptability index (percentage) for each formulation of pequi sweet breads offered to the children (n = 90) interviewed at the municipal elementary school located in Lavras – Minas Gerais, Brazil.**

Scores and hedonic scale	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
1 “I hated”	2.20	1.10	4.40	2.20	2.20	1.10	5.50	3.30
2 “I did not like”	-	2.22	5.60	7.80	3.30	3.30	2.20	3.30
3 “Indifferent”	8.90	10.00	6.70	11.10	5.60	4.40	12.20	13.30
4 “I liked it”	18.90	13.30	16.70	22.20	20.00	14.40	17.80	16.70
5 “I loved it”	70.00	73.30	66.70	56.70	68.90	76.70	62.20	63.30
Σ 4 “I liked it” and 5 “I loved it”	88.89[b]	86.67[b]	83.33[b]	78.89[c]	88.89[b]	91.11[a]	80.00[b]	80.00[b]

Notes: **T_1: standard formulation; T_2: 2.5% PHF; T_3: 20% PPF; T_4: 2.5% PHF + 20% PPF; T_5: 35% PP; T_6: 2.5% PHF + 35% PP; T_7: 20% PPF + 35% PP; T_8: 2.5% PHF + 20% PPF + 35% PP. Abbreviations of the terms of each formulation (T_1 - T_8): PHF: pequi husk flour; PPF: pequi pulp flour and PP: pequi pulp. The sum followed by the same letters do not differ from each other by the Tukey test at 5% probability.**

replacing 35% of the pequi pulp, reductions in moisture content (T_5, T_6, T_7 and T_8), however, the increase in the level of substitution of flour and pequi pulp (T_3, T_4, T_7 and T_8), culminated in the increase in lipid content, glycid fraction and energy value. All sweet bread formulations presented high sensory acceptance, especially the formulation with pequi husk flour and pequi pulp substitution (T_6), since they presented the highest acceptance percentage.

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