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Tannin-sorghum flours in cream cheese: Physicochemical, antioxidant and sensory characterization

Vinícius Tadeu da Veiga Correia[a,*], Danielle Fátima D'Angelis[a], Amanda Neris dos Santos[a], Elder Felipe Silva Roncheti[b], Valéria Aparecida Vieira Queiroz[c], José Edson Fontes Figueiredo[c], Washington Azevedo da Silva[d], Andreza Angélica Ferreira[a], Camila Argenta Fante[a]

[a] Department of Food, Faculty of Pharmacy, Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, MG, 31270010, Brazil
[b] Instituto Federal do Pará (IFPA), Campus Marabá Rural, Marabá, PA, 68508970, Brazil
[c] Brazilian Agricultural Research Corporation (Embrapa) Milho e Sorgo, Sete Lagoas, MG, 35701-970, Brazil
[d] Department of Food Engineering, Universidade Federal de São João del Rei (UFSJ), Campus Sete Lagoas, Sete Lagoas, MG, 35701970, Brazil

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ABSTRACT

This study aimed to develop and characterize the nutritional, antioxidant, and sensory properties of different cream cheese formulations added with raw or extruded BRS305 sorghum flours (SF) with brown pericarp and tannins. Five formulations were elaborated: (F0) cream cheese without SF (control); (RF1%) cream cheese with 1% of raw SF; (RF2%) cream cheese with 2% of raw SF; (EF1%) cream cheese with 1% of extruded SF; (EF2%) cream cheese with 2% extruded SF. There was significant variation ($p < 0.05$) concerning color among treatments, and the EF2% formulation was the darkest colored. Samples containing SF had higher protein and lower fat contents than the control. The antioxidant capacity, total phenolic, and condensed tannins contents were higher in RF2% and EF2%. The EF2% and RF2% samples showed the highest values for firmness ($p < 0.05$). The sensory parameters aroma and spreadability were not different ($p > 0.05$) among the products. Regarding flavor, overall impression, and purchase intention, the samples added with raw flour presented the best results, demonstrating that the presence of SF, did not influence the acceptance of the cream cheese. Therefore, adding raw or extruded BRS305 SF in cream cheese might be a nutritionally, technologically, and viable sensorial option.

1. Introduction

Healthy food is one of the main factors associated with quality maintenance of life, driving research to develop new products, especially in the dairy industry. This segment offers tasty and attractive products, providing consumers with differentiated, accessible, simultaneously healthier foods with a particular functional appeal. In this market, dairy products, especially cheese, are essential due to their nutritional characteristics and technological diversity (Dantas et al., 2016).

The cheese preparation process consists of milk concentration, whereby solid components, especially fat and proteins, are concentrated, while the aqueous (whey) part is separated from the curd during conventional manufacturing. Cheese has high nutritional value, are sources of the proteins of high biological value (20%), lipids (24% in dry extract), carbohydrates (2,5%), mineral and vitamins (4%) (López-Expósito, Amigo, & Recio, 2012). Cheese also can be used as matrices in the process of cream cheese production.

Cream cheese is a soft cheese, mildly acidic in flavor, easy spread, and a creamy product, obtained from the curd fusion or by mixing the cheese with other ingredients such as milk cream, gums, and pasteurized milk (Brighenti, Govindasamy-Lucey, Jaeggi, Johnson, & Lucey, 2018). It has been used to replace butter and margarine in food diets since they tend to have a lower total caloric value in terms of fats prepared with the Minas Frescal, ricotta, or cottage cheese curd. Cream cheese can also be added with fine herbs or cereals, for example chia and quinoa, to improve the texture, flavor, and increase of the product's nutritional properties (Lemes et al., 2016).

* Corresponding author.
E-mail addresses: viniciustadeu18@hotmail.com (V. Tadeu da Veiga Correia), danielledangelis7l@hotmail.com (D.F. D'Angelis), amandaneriss@gmail.com (A. Neris dos Santos), elderroncheti@gmail.com (E.F. Silva Roncheti), valeria.vieira@embrapa.br (V.A. Vieira Queiroz), jose.edson@embrapa.br (J.E. Fontes Figueiredo), was@ufsj.edu.br (W. Azevedo da Silva), andrezaferreira@ufmg.br (A.A. Ferreira), camilafante@ufmg.br (C.A. Fante).

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Among the most produced cereals globally, sorghum (*Sorghum bicolor* L.) stands out due to its high versatility and agronomic advantages as more tolerant to climates with low water availability (Paiva et al., 2017). Moreover, sorghum is a gluten-free cereal and an excellent alternative for producing food for celiac people. However, sorghum flours from different genotypes are different in their chemical and nutritional composition, thus, changing the products' technological and sensory processes to which they are added (Martino et al., 2012).

The sorghum BRS 305 (with tannin and brown pericarp) presents significant concentrations of resistant starch (52.26%), fiber (20.2%), and bioactive compounds, such as anthocyanins (0.26 mg equivalent luteolinidine/g) and condensed tannins (57.1 mg equivalent of catechin/g sample) (Correia et al., 2021; Oliveira et al., 2020; Teixeira et al., 2016). These are secondary compounds produced by plants, have antioxidant activity capable of scavenging free radicals that protect and promote human health (Anunciação et al., 2019; Moraes et al., 2012).

The use of sorghum as human food, grains, or flours requires some processing before consumption, such as cooking (Moraes et al., 2020), extrusion (Bernardo et al., 2019), and irradiation (Mukisa et al., 2012). However, most of these processing methods affect the antioxidant profile, staining, and texture of the products. Thus, before adding sorghum flour to dairy products, it is necessary to choose the best processing method to maximize their health benefits and acceptance by the consumers (Oliveira et al., 2020).

The extrusion process applied to sorghum flour has the advantages of improving starch digestibility and protein availability, increase fibers (11.94%–12.58%) and carbohydrates (67.58%–70.76%), and decrease lipid (3.09%–1.42%) contents in the processed samples (Campelo et al., 2020). Thus, the development of cream cheese added with sorghum flour having a high content of bioactive compounds may have improved functional properties, meeting the consumers' demand for healthier and tastier foods.

This study represents the first scientific approach about the incorporation sorghum flour in cream cheese formulations and aimed to develop and characterize the nutritional, antioxidant, and sensory properties of different cream cheese formulations added with raw or extruded sorghum flours obtained from the sorghum BRS 305 genotype with brown pericarp and tannins.

2. Material and methods

2.1. Reagents

The reagents of analytical grade hydrochloric acid, sulfuric acid, boric acid and sodium hydroxide were acquired from Synth (Diadema, SP, Brazil). Gallic acid and metanol were acquired from Neon (São Paulo, SP, Brazil). The 2,2′-azinobis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS), 6-hydroxy2,5,7,8-tetramethylchromane-2-carboxylic acid (Trolox), catechin, vanillin, Folin-Ciocalteu and ethanolamine were acquired from Sigma Aldrich (St. Louis, MO, USA).

2.2. Raw sorghum flour (RF) and extruded sorghum flour

The sorghum flour of the BRS 305 genotype was provided by Embrapa Milho e Sorgo, Sete Lagoas, Minas Gerais, Brazil. The raw flour (RF) samples were packed in polyethylene plastic bags and transported in isothermal boxes to the Nuclear Technology Development Center, where they were treated with gamma irradiation to prevent the cream cheese contamination by microorganisms. The gamma irradiation dose of 5 kGy was applied to samples for 247 s, with a dose rate of 1212.57 Gy/h and a distance of 29 cm from the target material. This step was performed in a multipurpose panoramic irradiator PTW LS01 and secondary standard dosimeter, using a commercial source of cobalt-60. The irradiated samples were kept under refrigeration (4 ± 2 °C).

The extruded sorghum flour (ES) of BRS 305 was processed at Embrapa Agroindustria de Alimentos (Rio de Janeiro, Brazil) in a twin-screw extruder model Evolum 109 HT 25 (Clextral, Firminy, France) with a circular matrix of four holes of equal diameter, at a constant speed of 40.32×g, and temperature zones of 30, 30, 60, 90, 100, 100, 120, 120, 150 and 150 °C for output supply. The thread diameter was 25 mm, total length configured in a screw of 1000 mm, generating a global ratio of 40, circular openings of 3.8 mm in diameter, and 9 mm in length. Extruded were collected, dried in forced air kiln at 60 °C for 4 h, and ground in a disc mill, followed by hammer mill (0.8 mm opening) to obtain the final product (Vargas-Solórzano, Carvalho, Takeiti, Ascheri, & Queiroz, 2014). The extruded sorghum flour was not subjected to gamma irradiation because it had already been heat-treated by the extrusion process.

2.3. Raw materials for cream cheese production

The pasteurized whole cow's milk, calcium chloride, lactic acid, rennet, milk cream, xanthan gum and salt, used in the cream cheese formulations, were acquired from local markets at Belo Horizonte city, Minas Gerais, Brazil.

2.4. Cream cheese processing

For the cream cheese processing, three repetitions of Minas Frescal cheese were prepared as follows. Pasteurized whole milk (with 6,00 g/ 200 mL of fat total) heated to 38 °C was used (ideal temperature for the coagulant agent), followed by the addition of calcium chloride (2.5 mL.5 L^{-1} milk), lactic acid (2.5 mL.5 L^{-1} milk), and rennet (4 mL.5 L^{-1}), and remaining at rest for 40 min until coagulation. After the coagulation, the curd was cut, agitated, and the whey discarded. The products were shaped in circular forms, packed in polyethylene plastic films, and stored under refrigeration (7 ± 2 °C) until the cream cheese processing.

For each repetition of Minas Frescal cheese previously prepared, five formulations of cream cheese (treatments) were obtained. The proportions of ingredients in the cream cheese are described in Table 1. The cream cheese curd was prepared by adding a xanthan gum diluted in pasteurized cow milk heated to 65 °C to promote a greater tension between hydrocolloids and casein molecules and obtain a better texture. Then, the curd was processed in an industrial blender (Poli Metallurgical Siemsen, model TR-02, frequency of 60 Hz, and power of 245 W), with fresh milk cream, sliced Minas Frescal cheese, salt, and sorghum flour (except in control), according to Buriti, Cardarelli, and Saad (2008).

The concentrations of raw or extruded sorghum flours added to the products were determined according to the studies of Oliveira et al. (2020) and Lemes et al. (2016). The cream cheese formulations were stored under refrigeration (7 ± 2 °C) in glass pots, and their physicochemical, antioxidant, and sensory properties were performed one day

Table 1
Ingredients used in control and cream cheese formulated with raw (RF) or extruded (EF) sorghum flour of BRS 305.

	Cream cheese treatments				
Ingredients	F0	RF1%	RF2%	EF1%	EF2%
Minas Frescal cheese	60%	60%	60%	60%	60%
Pasteurized milk	29%	28%	27%	28%	27%
Milk cream	9.7%	9.7%	9.7%	9.7%	9.7%
RF BRS 305*	–	1%	2%	–	–
EF BRS 305**	–	–	–	1%	2%
Salt	0.8%	0.8%	0.8%	0.8%	0.8%
Xanthan gum	0.5%	0.5%	0.5%	0.5%	0.5%
Total	100%	100%	100%	100%	100%

- No addition. Treatments: F0 (control sample), RF1% (sample with 1% RF), RF2% (sample with 2% RF), EF1% (sample with 1% EF), EF2% (sample with 2% EF). *Raw whole sorghum flour: moisture 11.2%; ash 2.86%; protein 13.0%; fat 3.60%; carbohydrate 60.3% **Extruded sorghum flour: moisture 8.21%; ash 1.42%; protein 12.48%; fat 1.72%; carbohydrate 76.17% and granulometry 300 μm.

after processing.

2.5. Physicochemical analysis of cheese and cream cheese formulations

The physicochemical analyses were performed by three replicates of each cream cheese treatment, with a triplicate for each sample. The moisture (AOAC 926.08), protein (AOAC 991.23) and ash (AOAC 920.108) contents were determined according to Association of Official Analytical Chemists (AOAC, 2012). The gravimetric method measured the moisture content using a forced-air circulation oven at 105 °C, the protein by Kjeldahl technique using a correction factor of 6.38, and the ash by incineration in muffle at 550 °C. The lipid content was determined by Gerber butyrometer methodology (Brasil, 2006). The carbohydrate contents were calculated by the equation [100 - (moisture + protein + lipid + ash)].

The color parameters were measured at 10 random positions using the Cielab system in colorimeter Konica Minolta (model CM-2600D, Osaka, Japan). The equipment was previously calibrated on a white surface and in sequence the light projection tube was placed immersed in the sample reading the values of the coordinates L* (lightness), a* (-a* = greenness and +a* = redness), and b* (-b* = blueness and +b* = yellowness) (Wyszecki & Stiles, 2000).

The pHmeter (MS Tecnopon) was calibrated using pH 4 and 7 buffers and pH determined by a potentiometer in 10 g of samples homogenized with 50 mL of distilled water (Sukarminah, Lanti, Wulandari, Lembong, & Utami, 2019). The titratable acidity (TA) of the cheese dough was measured by titrimetry, and the results were expressed as a percentage (%) of lactic acid.

2.6. Antioxidant properties of the cream cheese formulations: total phenolic compounds (TPC), condensed tannins (CT), and antioxidant capacity (AC) by ABTS method

The cream cheese formulations were freeze-dried in a lyophilizer (L101 LIOTOP - Liobras), under vacuum at −50 °C for 92 h. The TPC, CT, and AC contents were determined in freeze-dried samples using a spectrophotometer (Instrutherm® Model UV-2000 A), and the absorbances were read at 620 nm, 500 nm, and 734 nm, respectively. The TPC content was determined by the method using *Folin Ciocalteau* reagent, according to Kaluza, Mcgrath, Roberts, and Schroder (1980), and the results were expressed in mg of equivalent gallic acid (EGA). g^{-1} sample, on a dry basis (db).

CT was determined by the vanillin/HCl method described by Price, Van Scoyoc, and Butler (1978), and the results were expressed in mg of equivalent catechin (EC). g^{-1} sample, on a dry basis (db). The antioxidant capacity was determined by the ABTS method (Awika, Rooney, Wu, Prior, & Cisneros-Zevallos, 2003). The results were expressed in μmol equivalent Trolox.g^{-1} on a dry basis (db).

2.7. Instrumental texture

The texture profile was determined using the double compression test in plastic packages, using an aluminum cylinder of 35 mm. The cream cheese texture was evaluated in a texture analyzer TAXTPLUS (Stable Micro Systems), and the data were collected through the *Exponent Lite* program, version 5.1.1.0, 2010. The primary attributes of firmness, adhesiveness, springiness, cohesiveness, resilience, chewability, and the secondary gumminess parameter were evaluated. For this purpose, the following conditions were used: samples with 2 cm (height) x 5 cm (diameter), the temperature of 7 °C, distance, speed, and compression interval of 10 mm, 1 mm/s and 5 s, respectively (Buriti et al., 2008).

2.8. Microbiological analysis

The microbiological analysis was carried out in triplicate. For *Salmonella* sp., portions of 25 g of each cream cheese formulation were aseptically transferred to individual sterile bags containing 225 mL (w/v) of 1% buffered peptone water (BPW), homogenized, and diluted in the same solution. One milliliter and 0.1 mL of BPW were transferred to 10 mL of Selenite cystine broth and 10 mL of Rappaport-Vassiliadis, respectively. The broth was straked in Salmonella-Shigella agar (SS), Hektoen Enteric agar (HE), and Xylose Lysine Deoxycholate Agar (XLD agar) and incubated at 35 °C for 48 h.

The most probable number (MPN) of total and thermotolerant coliforms in the samples was determined by applying the multiple tube technique. For *Staphylococcus* spp., aliquots of 0.1 mL of dilutions were sown in Baird-Parker agar plates (Acumedia, Lansing, MI, USA) incubated at 35–37 °C for 48 h.

The identification and colony counting presenting typical and atypical characteristics were performed according to the acceptable limits for cream cheese established by the Technical Regulation on Microbiological Standards for Food, Resolution Nº January 12, 2001 (Da Silva et al., 2010).

2.9. Sensory analysis

This study was approved by the Ethics Committee on Research with Human Beings of the Universidade Federal de Minas Gerais, under protocol number (CAAE-09233419.0.0000.5149/2019). Sensory evaluation was performed in a single session in the Sensory Analysis Laboratory of the Universidade Federal de São João del-Rei - Campus Sete Lagoas, in individual cabins under white light. The volunteers consisted of students, professors, staff, and visitors invited through a university document.

The voluntary participants have signed the Informed Consent Form for Research with Human Beings. It was also completed an application with relevant questions aiming to raise the socio-economic profile of the evaluators. It was excluded the questionnaires from people who claimed some dietary restriction to milk (lactose intolerance and allergy to proteins present in cow's milk) or other ingredients in the formulation, as well as individuals with health problems and those using medicines that alter sensory perception.

The sensory quality of the cream cheese was evaluated by 60 non-trained panelists using affective tests of acceptance and purchase intention and the descriptive test check-all-that-apply (CATA). For the acceptance test, a hedonic scale of 9 points ranging from 1 "extremely disliked" to 9, "I liked extremely" for each attribute evaluated: color, aroma, texture, flavor, global impression, spreadability (SPR), and an attitude scale (FACT) of 5 points was used to verify the purchasing attitude of consumers.

In the same panel, the evaluators answered the questions of the CATA test, which included 18 sensory attributes related to the cream cheese characteristics: sandy, cream flavor, cheese odor, acid, flour odor, bitter, cheese flavor, yellowish-white color, fluid, salty, tasteless, opaque, viscous, creamy, rosy, brightness, whole, and milk odor. The terms were selected from previous studies with cream cheese, curd, and cheese and complemented with those raised by a team of five researchers (Brighenti, Govindasamy-Lucey, Lim, Nelson, & Lucey, 2008; Oliveira et al., 2017).

The cream cheese samples were served in disposable plastic cups, randomly and presented in a balanced way, together with 200 mL of water (for cleaning the palate). Each panelist was asked to analyze the evaluation form containing the attributes and mark all the terms considered appropriate to describe each target sample.

2.10. Statistical analysis

The experiment was conducted according to a completely randomized design. The processing of instrumental data and sensory tests of acceptance and purchase intention were submitted to variance analysis (ANOVA) using the Software SPSS 15.0. The formulations as a fixed effect and the repetitions considered a random term after verifying the initial premises of homogeneity and normality by the Shapiro-Wilk and Levene tests. The Tukey test was used to determine the significant differences between treatments ($p < 0.05$).

The multivariate method of principal component analysis (PCA) based on a correlation matrix was performed to evaluate the relationship among all variables measured in cream cheese formulations separately. The PCA analyses were performed using software Statistica® version 13.

For the CATA descriptive test, the citation frequency each sensory attribute was determined by counting the number of evaluators who used the terms to describe the samples. Correspondence Analysis (CA) was calculated, by contingency classifications, of all results sensory presented in this study, using the SensoMaker software.

3. Results and discussion

3.1. Physicochemical analysis of Minas Frescal cheese

Originally from the Minas Gerais state, Brazil, the Minas Frescal cheese are food for immediate consumption since the expressive moisture content influences their texture and flavor characteristics (Magenis et al., 2014). According to the Technical Regulation of Identity and Quality of Minas Frescal Cheese (Brasil, 1997), the Minas Frescal cheese developed in this study with 62.16% of moisture can be classified as a "cheese of very high humidity" (not less than 55%). The moisture content significantly influences food quality due to its association with microbial contamination and physicochemical variations (Visotto, Oliveira, Prado, & Bergamini, 2011). The fat content was 32.15%, and the cheese was classified as a semi-fat (25–44.9% fat, in dry extract) (Brasil, 2004). The acidity was 0.04% lactic acid, and the ash and carbohydrates contents were 2.52% and 2.24%, respectively. Regard protein, the content was 20.91%, following the Ministério da Agricultura, Pecuária e Abastecimento146/1996 recomendation (Brasil, 1996), where the minimum percentage should be 20%.

3.2. Physicochemical analyses of cream cheese

The physicochemical compositions of cream cheese are shown in Table 2. The control cream cheese differed in lightness and chromaticity a* and b* values concerning all other treatments ($p < 0.05$). A significant variation of a* value (a red axis with positive values) was observed for samples containing SF. The EF2% and F0 presented, respectively, the highest and the lowest value of a*. Regarding lightness (L*), SF addition reduced this parameter with more excellent opacity in these treatments than cream cheese without sorghum flour.

This fact can be explained because the BRS 305 sorghum grains have brown pericarp with significant concentrations of natural food dyes as anthocyanins (Queiroz et al., 2014), which visibly gave a rosy tint to cream cheese developed with SF compared to the control, which presented higher b* value and yellowish-white color.

Khalifa, Abdeen, El-Shafei, and Mohamed (,) reported similar finding on cheese spread added with quinoa flour. The L* value decreased when the quinoa level was increased. The same condition was reported by Ardabilchi Marand, Amjadi, Ardabilchi Marand, Roufegarinejad, and Jafari (2020) when they added flaxseed powder in yogurts. The original darker color of the flaxseed is similar to the BRS 305 sorghum flour of our study.

The color parameter significantly affects the consumer's acceptance of dairy products and, consequently, their industrialization and marketing (Zare, Boye, Orsat, Champagne, & Simpson, 2011). Thus, it is imperative to evaluate the sensory characteristics of the products developed.

The cream cheese samples did not differ in moisture, ash, and carbohydrate contents ($p > 0.05$). Concerning F0, the samples containing raw or extruded sorghum flours showed higher protein content and lower fat concentrations ($p < 0.05$). This result indicates that the use of BRS 305 sorghum flour contributed to improving the nutritional quality of the cream cheese.

The lower fat content of cream cheese samples with SF was proportional to the milk content added during the product preparation. Lemes et al. (2016) evaluated cream cheese added with chia and quinoa flours and obtained similar lipid concentrations (mean of 8.5%) to those found in the present study. These results demonstrate the feasibility of the industrial development of cream cheese added with sorghum flour because they meet the consumers' demand for foods with low fat and high protein contents.

Also, the pH is an important parameter to all cheese characterization because it directly influences the structure and rheological properties of the products, affecting the chemical interactions among its main structural components (proteins, water, and minerals) (Gomes & Penna, 2010). The pH of the samples were 6.71, 6.60, 6.60, 6.68, and 6.59 for F0, RF1%, RF2%, EF1%, and EF2%, respectively, demonstrating that the raw or extruded SF addition did not significantly change this parameter ($p > 0.05$).

Table 2
Physicochemical characterization of the control and cream cheese added with raw* (RF) or extruded** (EF) sorghum flours of the BRS 305 genotype.

Components	F0	RF1%	RF2%	EF1%	EF2%
L*	92.99 ± 0.39^a	87.42 ± 0.42^b	85.88 ± 0.27^c	86.05 ± 0.52^c	83.82 ± 0.27^d
a*	-0.72 ± 0.06^e	1.98 ± 0.03^d	3.26 ± 0.13^b	2.82 ± 0.25^c	3.88 ± 0.18^a
b*	11.98 ± 0.30^a	10.34 ± 0.05^{bc}	10.56 ± 0.51^b	10.01 ± 0.19^{bc}	9.71 ± 0.24^c
Moisture (%)	68.86 ± 0.38^a	67.80 ± 1.94^a	66.66 ± 1.19^a	68.35 ± 0.81^a	65.05 ± 4.18^a
Proteins (%)	10.57 ± 0.35^b	14.27 ± 0.22^a	14.50 ± 1.60^a	13.87 ± 0.54^a	13.91 ± 1.26^a
Fat (%)	10.00 ± 0.00^a	9.33 ± 0.58^b	8.50 ± 0.87^b	9.17 ± 0.29^b	8.50 ± 0.87^b
Ash (%)	3.75 ± 0.05^a	3.77 ± 0.37^a	3.93 ± 0.73^a	4.51 ± 1.39^a	4.29 ± 1.33^a
Carbohydrates (%)	6.82 ± 2.61^a	4.83 ± 2.61^a	6.41 ± 1.85^a	4.10 ± 1.93^a	8.25 ± 5.41^a

- Treatments: F0 (control sample), RF1% (sample with 1% RF), RF2% (sample with 2% RF), EF1% (sample with 1% EF), EF2% (sample with 2% EF). Means with different letters, in the same column, are significantly different by the Tukey test ($p < 0.05$). *Raw whole sorghum flour: L* = 68,30, a* = 6,36, b* = 13,18. **Extruded sorghum flour: L* = 62,20, a* = 9,18, b* = 17,26.

3.3. Antioxidant properties

The BRS 305 sorghum genotype has, genetically, high concentrations of CT (57.10 mg equivalent of catechin/g sample), TPC (19.70 mg gallic acid equivalents/g) and AC (186.7 (mmol Trolox equivalent/g), respectively (Do Prado et al., 2019). The antioxidant concentrations for cream cheese formulations are shown in Table 3. The RF2% and EF2%

Table 3
Total phenolics (mgEAG.g^{-1}, db), condensed tannins (EC.g^{-1}, db) and antioxidant activity measured by the ABTS method (μmol Trolox eq.g^{-1}, db) of the control and cream cheese added with raw sorghum flours (RF) or extruded sorghum flours (EF) of the genotype BRS 305.

Cream cheese	TPC	CT	AC
F0	0.87 ± 0.02^d	nd	333.18 ± 5.32^c
RF1%	0.96 ± 0.02^c	nd	379.43 ± 4.89^b
RF2%	1.21 ± 0.07^a	0.75 ± 0.06^a	423.37 ± 15.12^a
EF1%	1.05 ± 0.01^b	nd	395.07 ± 11.27^b
EF2%	1.19 ± 0.06^a	0.25 ± 0.09^b	454.96 ± 19.97^a

- Nd: Not detected, db: in dry base. Treatments: F0 (control sample), RF1% (sample with 1% RF), RF2% (sample with 2% RF), EF1% (sample with 1% EF), EF2% (sample with 2% EF). Means with different letters, in the same column, are significantly different by the Tukey test ($p < 0.05$).

treatments presented higher content TPC and AC than the others ($p < 0.05$).

CT was detected only in cream cheese containing 2% of sorghum flours, and in RF2% the CT content was significantly higher than the EF2% ($p < 0.05$). Dlamini, Taylor, and Rooney (2007) observed that the extrusion cooking reduced the tannin content in different sorghum genotypes. Additionally, Queiroz et al. (2018) report that, during the extrusion process, the condensed tannins can interact with carbohydrates and proteins, forming insoluble and less extractable complexes, reducing the concentrations of this compound. However, this processing leads to decreased nutrient metabolizable energy and more excellent palatability in sensory terms (Cardoso et al., 2015).

It is essential to highlight those tannins in food are associated with reduced protein digestibility and feed efficiency in animals and humans. However, these compounds are also associated with beneficial immunomodulatory, anticancer, antioxidant, anti-inflammatory, antithrombotic, and cardioprotective effects (Arbex et al., 2018; Wu et al., 2012). Within this context, several studies have demonstrated the importance of tannin-sorghum to develop new products with high antioxidants and bioactive compounds contents that may contribute to human healthy (Queiroz et al., 2018, 2020).

Tannins can also bind to starch and help reduce caloric availability in diets for individuals seeking to lose weight (Moraes et al., 2012; Wu et al., 2012). According to Dykes, Rooney, Waniska, and Rooney (2005) and Wu et al. (2016), tannins are the main compounds contributing to increase the antioxidant capacity and phenolic compounds in specific sorghum genotypes, this explains the higher antioxidant capacity presented in the formulations of cream cheese containing 2% of raw and extruded BRS 305 tannin-sorghum flours.

Lopes et al. (2019) observed higher concentrations of condensed tannins and total phenolic compounds in unfermented milks added with extruded BRS 305 genotype compared to the control product formulated with extruded corn. In turn, Oliveira et al. (2020) observed higher AC, CT, and TPC concentrations in Greek yogurts prepared with 4% of BRS 305 sorghum flour. These finds suggest a higher functional potential of dairy products developed with tannin-sorghum than those made with tannin-free sorghum.

In the present study, we also observed that the highest antioxidant capacity formulations also showed the highest total phenolics and condensed tannins. The control formulation had the lowest levels of the analyzed variables, reinforcing the importance of sorghum flours in dairy products.

3.4. Instrumental texture

The texture profiles of cream cheese with and without SF are shown in Table 4. The treatments F0, RF1%, and EF1% showed similar behavior regarding firmness, cohesiveness, gumminess, and chewability, not differing significantly among them ($p > 0.05$). However, there was a significant increase ($p < 0.05$) in the mean of these parameters in both treatments containing 2% SF.

The adhesiveness, expressed in, module was high ($p < 0.05$) in the treatments with higher percentages of SF, providing the formation of a more resistant structure, which requires greater strength to remove the cheese on the contact surface of the mouth, usually the tongue or palate (Karaman & Akalin, 2013). Formulations EF2% and RF2%, with the highest SF and less cream content, had the highest firmess. This found suggests that the high capacity of sorghum flour to absorb water associate with a low fat concentration, is responsible for smoothness and creamiss and can contribute to a greater resistance to deformation (Lemes et al., 2016).

The EF2% cream cheese showed higher gumminess values and chewability than other treatments ($p < 0.05$). This result may be associated with the extrusion process of the sorghum flour and its amount added to the products. The extrusion process provides new formats and structures to the flours with different functional and nutritional characteristics, reducing their surface area and interaction among the food surfaces, thus, causing variation of these attributes (Becker, Eifert, Soares Junior, Tavares, & Carvalho, 2014).

Table 4
Instrumental texture analysis on the control and cream cheese added with raw flours (RF) or extruded (EF) flours of the sorghum genotype BRS 305.

Parameters	F0	RF1%	RF2%	EF1%	EF2%
Firmness (N)	386.8 ± 126.2^{c}	477.1 ± 23.9^{c}	702.1 ± 130.6^{b}	479.8 ± 7.3^{c}	978.0 ± 90.7^{a}
Springiness	0.90 ± 0.02^{a}	0.90 ± 0.05^{a}	1.00 ± 0.03^{a}	1.00 ± 0.01^{a}	1.00 ± 0.03^{a}
Cohesiveness	0.4 ± 0.02^{b}	0.4 ± 0.01^{b}	0.5 ± 0.01^{a}	0.4 ± 0.01^{b}	0.5 ± 0.03 ^{a}
Gumminess (N)	183.0 ± 55.9^{c}	198.3 ± 8.6^{c}	344.0 ± 58.9^{b}	207.0 ± 3.7^{c}	492.3 ± 47.7^{a}
Chewability (N)	172.7 ± 52.5^{c}	185.7 ± 9.5^{c}	328.1 ± 60.2^{b}	191.9 ± 14.6^{c}	475.4 ± 37.8^{a}
Resilience	0.02 ± 0.01^{a}	0.02 ± 0.0^{a}	0.02 ± 0.01^{a}	0.03 ± 0.00^{a}	0.03 ± 0.00^{a}
Adhesiveness (N.m)	2240 ± 205.9^{c}	2476 ± 98.7^{bc}	2615 ± 292.7^{bc}	2773 ± 157.6^{ab}	3165 ± 480.2^{a}

- Treatments: F0 (control sample), RF1% (sample with 1% RF), RF2% (sample with 2% RF), EF1% (sample with 1% EF), EF2% (sample with 2% EF). The means with different letters, in the same line, are significantly different by the Tukey test ($p < 0.05$).

The resistant starch and the dietary fibers can complex (via hydrogen bonds) with protein aggregates, becoming part of the structural network formed in the product (Batista et al., 2017), resulting in greater firmness in the treatments developed with sorghum flour. Batista et al. (2017) developed symbiotic fermented milk flour at different concentrations and observed that the treatments containing the highest flour content (3 and 5%) showed a greater firmness.

For springiness and resilience, there was no significant difference among the treatments developed ($p > 0.05$), which is following the results obtained by Buriti et al. (2008) evaluating the instrumental texture of symbiotic cream cheese added with *Lactobacillus paracasei* and inulin.

3.5. Principal component analysis (PCA)

Fig. 1 shows the PCA for the physicochemical characteristics and antioxidant attributes of cream cheese formulations. Two principal dimensions (Dim1 and Dim2) were evaluated and, together, they explained 68.55% of the total variance of the physicochemical and antioxidant characteristics of the formulations; PC1 explained the majority of the variations (52.45%). According to the graphic loadings, the parameters of texture, antioxidants, proteins, and chromaticity a* were positively correlated with PC1, while fat, lightness, chromaticity b*, and moisture were negatively correlated with PC1. Carbohydrates were negatively correlated and minerals positively with PC2.

The scores plot indicated different physicochemical and antioxidant aspects among the formulations. According to the graphic loadings, the formulations of RF2% and EF2% were characterized by higher TPC, CT, antioxidant capacity, protein, higher firmness, gumminess, cohesiveness, springiness, and chewability. Contrastingly, they presented lower lipid contents and lower values of lightness and chromaticity b*. These results can be explained by the amount of the BRS 305 sorghum flour added to the 2% SF formulations associated with the antioxidant characteristics with high CT and TCP content.

Concerning texture, the results can be attributed to the considerable amount of starch (70%–80), the main component of the sorghum flour (Da Cruz, Da Silva, Dos Santos, Zavareze, & Elias, 2015). Starch is the most responsible for the technological attributes characterizing most of the processed products. Starch contributes to food's texture properties with many industrial applications such as thickener, colloid stabilizer, gelling agent and volume, adhesive, and water retention (Singh, Singh, Kaur, Sodhi, & Gill, 2003).

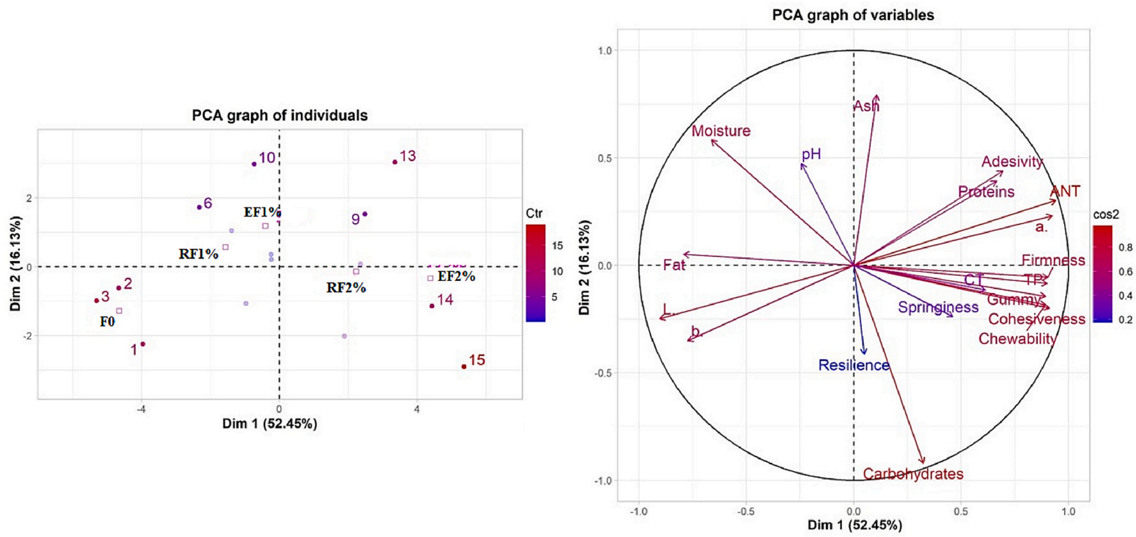

Fig. 1. Score and loading plots of PCA for physicalchemical, texture and antioxidant characteristics of the control and the cream cheese added with raw flour (RF) or extruded (EF) flour of the sorghum genotype BRS 305. Treatments: F0 (control sample), RF1% (sample with 1% RF), RF2% (sample with 2% RF), EF1% (sample with 1% EF), EF2% (sample with 2% EF).

The results of the PCA corroborate those obtained analytically. According to Do Prado et al. (2019) and Oliveira et al. (2020), principal component analysis adequates a basis for determining patterns or data structure and verifying the importance of individual parameters facilitating the understanding of datasets in studies aiming at the development of new products.

3.6. Microbiological analysis

For products such as cream cheese, the maximum limits allowed in the Brazilian legislation (12/2001) are 5.0×10^3 fecal coliforms units/g of a sample at 45 °C, 1.0×10^3 CFU/g, *Staphylococcus* sp. and absence of *Salmonella* sp. in 25 g of product (Brasil, 2001). All cream cheese developed was under the current legislation; thus, they could be evaluated as sensory safe (Table 5).

3.7. Sensory

Sixty evaluators participated in the sensory analysis. Sixty-five percent of them declared themselves female, and 35% male. Only 8.33% had never consumed cream cheese, 33.33% consumed sporadically, 42.34% rarely, 10% frequently, 6% daily, and 55% already knew sorghum flour. More than 75% of the evaluators had a family income in a range of 1–5 minimum ages, 65% had ages ranging from 18 to 25 years, and 70% of the voluntaries were undergraduate students of different courses of UFSJ- *Campus* Sete Lagoas.

Regarding the acceptability of the cream cheese formulations, there was no difference ($p > 0.05$) for the attributes color, aroma, texture, and spreadability (Table 6), with sensory notes ranging, on average, from 6.78 to 8.12 (from I liked it slightly to I liked it extremely, however, about flavor, the treatments RF1%, RF2%, and EF1% ($p < 0.05$) were more accepted than the EF2%. To overall impression, only treatments with 2% of sorghum flour differed from each other, and the cream cheese with raw sorghum flour had the highest scores. Thus, this result showed that the addition of raw sorghum flour to cream cheese formulations is more feasible in terms of sensory and operational costs since it does not require more complex and costly processing.

According to the purchase intention, tannin-sorghum flour in the cream cheese samples did not affect the evaluator's acceptance and purchase intention since these products' sensory notes were similar to those obtained by the control sample (commonly consumed by the population). One hypothesis on this excellent acceptance is that xanthan gum, an ingredient added in all formulations, may have complexed with tannin, reducing its astringency. According to Carvalho, Póvoas, Mateus, and De Freitas (2006), polysaccharides such as pectin, xanthan, and Arabic gum are effective inhibitors of protein precipitation by polyphenols (condensed tannins).

Oliveira et al. (2020) developed a Greek yogurt with the addition of BRS 305 sorghum flour and observed that the formulation with 2% of SF was accepted ($p < 0.01$) with a mean (7.05) situated between the hedonic terms: "I liked moderately" and "I liked a lot" and samples with 4% of SF obtained an average of 6.17 ("slightly-liked moderately"). These results show an excellent sensory acceptance of dairy products developed with the BRS 305 tannin-sorghum flour and demonstrate the sensory and commercial potential for adding sorghum flour to other products.

Queiroz et al. (2018) developed two powdered drink mixes with extruded sorghum flours, one with tannin and the other without tannin. After sensory analysis, it was verified that the product containing tannin presented greater overall acceptability with a mean of 8.21 (with acceptance percentage above 90%).

Thus, in terms of acceptability and purchase intention, the cream cheese developed in this experiment has a significant potential for insertion in the consumer market. Sensory analysis of cream cheese, by the CATA test, showed that the formulations were applicable to pre-established sensory attributes (descriptors), described in the "Material and Methods".

The control sample, that was directly attributed to the term "Yellowish-white", differed from the samples with sorghum flour added,

Table 5
Microbiological analysis of the control and cream cheese added with raw (RF) or extruded (EF) sorghum flours of the BRS 305 genotype.

Cream cheese	Coliforms 45 °C (NPM/g)	*Staphylococcus* sp. (Log CFU/g)	*Salmonella* sp. (25 g)
F0	<5.0	<1.0	ABS
RF1%	<5.0	<1.0	ABS
RF2%	<5.0	<1.0	ABS
EF1%	<5.0	<1.0	ABS
EF2%	<5.0	<1.0	ABS

ABS: absence. Treatments: F0 (control sample), RF1% (sample with 1% RF), RF2% (sample with 2% RF), EF1% (sample with 1% EF), EF2% (sample with 2% EF).

Table 6
Means of sensory attributes and purchase intention from the control and cream cheese added with raw flours (RF) or extruded (EF) flours of the sorghum genotype BRS 305.

Sensory attributes							
Treatments	Color	Aroma	Texture	Flavor	Overall acceptabillity	SPR	Purchase intention
F0	7.63^{a}	7.00^{a}	7.80^{a}	7.42^{ab}	7.40^{ab}	8.07^{a}	3.93^{ab}
RF1%	7.90^{a}	7.30^{a}	7.98^{a}	7.63^{a}	7.58^{ab}	8.12^{a}	4.17^{a}
RF2%	7.82^{a}	7.23^{a}	7.70^{a}	7.65^{a}	7.65^{a}	8.08^{a}	4.07^{ab}
EF1%	7.65^{a}	7.03^{a}	7.63^{a}	7.47^{a}	7.57^{ab}	7.93^{a}	3.98^{ab}
EF2%	7.42^{a}	6.80^{a}	7.77^{a}	6.78^{b}	7.00^{b}	8.10^{a}	3.60^{b}

Sensory attributes: 9 hedonic scale points: 9 = liked extremely liked; and 1 = I greatly disliked it. Intention to buy 5 points: 5 = certainly buy the product, and 1 = certainly would not buy the product.
- Means with different letters in the same column are significantly different by the Tukey test ($p < 0.05$).

which were positively attributed to the terms “Cheese flavor”, “Creamy”, “Cream flavor”, “Cheese odor”, “Milk odor”, “Rosy”, “Sandy”, “Viscous”, “Whole".

It should be noted that the control sample was not attributed to the term “Rosy” (0%), and that, among the samples analyzed, it was the most applicable to the term “Creamy” (87%). The RF2% and EF2% formulations were not assigned to the term “Acid".

The “Cheese flavor” and “Creamy” descriptors, were applicable above 50%, F0 (65%, 87%), RF1% (63%, 80%), RF2% (67%, 75%), EF1% (55%, 68%), EF2% (65%, 75%), respectively. The EF2% was not assigned once to the term “Fluid".

The results of CATA showed that, in general, it is possible to idealize that the EF2% sample was considered a cream cheese with “Cream flavor”, “Cheese flavor”, “Creamy” and “Rosy”. The EF1% formulation was considered a cream cheese, similar to EF2% except for its higher viscosity, and lower “Tasteless”. The RF1% and RF2% samples were applied to the same terms in a similar way. Thus, it is possible to add 2% of flour, without changing the sensory perception.

The graphical representation of the sensory terms used in the CATA method is shown in Fig. 2. Correspondence Analysis (CA) was applied by contingency, and a two-dimensional map was plotted with all sensory results. The first and second dimensions represent approximately 88.38% of the entire range of experimental data, with 70.95% and 17.43%, respectively.

By analyzing Fig. 2., it was possible to separate the treatments into three groups. The first group, consisting of EF2% treatment, developed with 2% extruded sorghum flour, was attributed to the characteristics: “tasteless” and “flour odor”. The control treatment (F0) differe from others and was associated to the attribute “white-yellowish color”. Finally, RF1%, RF2% and EF1% showed similar characteristics, most of the positive attributes, in addition to being linked to the attributes evaluated in the sensory analysis of acceptance and purchase intention.

Regarding the method used to describe the products, CATA becomes helpful to group the information perceptible to consumers of cream cheese from a list of attributes. Thus, the evaluators could simultaneously select several characteristics, allowing a description of the sensory parameters sequentially when tasting the food (Castura, Antúnez, Giménez, & Ares, 2016).

4. Conclusion

This study represents the first scientific approach of the incorporation raw or extruded sorghum flour in cream cheese formulations. The addition of tannin-sorghum flour provided higher concentration of proteins, condensed tannins and capacity antioxidant of formulations, improving their nutritional and antioxidant properties.

In technological terms, SF contributed to make the cream cheese rosy and with greater firmness. Regarding the sensory analysis, all treatments were accepted, demonstrating that there is no negative impact of the tannin-sorghum flour on the sensory attributes of the products. The sensory terms applicable in the formulations with sorghum flour are positively attributed to the characteristics that the sorghum itself

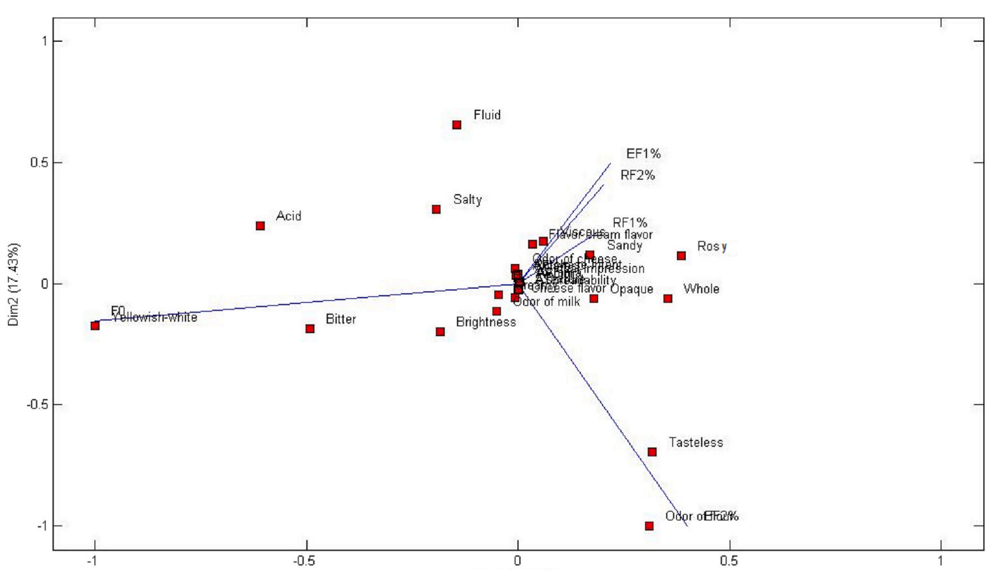

Fig. 2. Sensory descriptive map of five samples of cream cheese (vectors) and their sensory attributes used to describe them in two dimensions of the correspondence analysis on the frequency presented in the CATA and sensory acceptance (n = 60). Treatments: F0 (control sample), RF1% (sample with 1% RF), RF2% (sample with 2% RF), EF1% (sample with 1% EF), EF2% (sample with 2% EF).

provided to the food, with emphasis on color and texture.

The addition of raw sorghum flour to cream cheese formulations is more feasible in terms of sensory and operational costs, as it does not require previous processing by extrusion, which is more complex and costly. New products, such as cream cheese added with sorghum flour, meet market demand for viable, stable products with nutritional, functional, and sensory benefits to the human organism.

CRediT authorship contribution statement

Vinícius Tadeu da Veiga Correia: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft. **Danielle Fátima D'Angelis:** Formal analysis, Investigation. **Amanda Neris dos Santos:** Formal analysis, Writing – original draft. **Elder Felipe Silva Roncheti:** Formal analysis. **Valéria Aparecida Vieira Queiroz:** Writing – review & editing, Supervision, Resources. **José Edson Fontes Figueiredo:** Writing – original draft. **Washington Azevedo da Silva:** Formal analysis, Resources. **Andreza Angélica Ferreira:** Conceptualization, Writing – review & editing, Resources, Supervision. **Camila Argenta Fante:** Conceptualization, Writing – review & editing, Resources, Supervision.

Declaration of competing interest

Authors declare that there is no conflict of interest regarding the publication of this article.

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