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Greek yogurt with added sorghum flours: antioxidant potential and sensory acceptance

Yogurt griego adicionado de harinas integrales de sorgo: potencial antioxidante y evaluación sensorial

ABSTRACT

The aim of this study was to develop and evaluate the antioxidant characteristics and sensory acceptance of Greek yogurt with added whole sorghum flours (WSF) from genotypes BRS305 (tannin) and BR501 (tannin-free). Five formulations were elaborated: 1) Control (without WSF); 2) 2% BR501; 3) 4% BR501; 4) 2% BRS305 and 5) 4% BRS305 and evaluated for antioxidant capacity, total anthocyanins, total phenols, condensed tannins, sensory acceptance and purchase intention. The 4% BRS305 formulation presented higher antioxidant properties, but lower sensory acceptance. No significant difference was observed for: color, flavor and overall acceptability between the control and 2% BR501; nor for texture and overall acceptability between the control and 4% BR501. Principal component analysis explained that all variables associated with antioxidant properties were positively correlated with the first major component (PC1: 82.7%). The 2% and 4% BR501 formulations were more highly correlated with PC1 (92.7%), as well as the control in relation to sensorial characteristics. The addition of WSF BRS305 improved the antioxidant properties of yogurts and the addition of WSF BR501 did not interfere with the sensory acceptance of the formulations. The similarity of the sensory acceptance of the yogurt containing WSF from the BR 501 genotype to the control, opens perspectives for the insertion of sorghum in human food, using dairy products as suitable matrices, adding potential functionality to this type of product.

Keyword: Anthocyanins; Dairy products; Functional foods; Sorghum bicolor L. Moench; Tannins.

RESUMEN

El trabajo tuvo como propósito desarrollar y evaluar las características antioxidantes y la aceptación sensorial de yogurt griego con adición de harinas integrales de sorgo (HIS) de los genotipos BRS305 (con taninos) y BR501 (sin taninos). Cinco formulaciones fueron elaboradas: 1) Control (sin HIS); 2) 2% BR501; 3) 4% BR501; 4) 2% BRS305 y 5) 4% BRS305. Las formulaciones fueron evaluadas en función de su actividad antioxidante, antocianinas totales, fenólicos totales, taninos condensados, aceptación sensorial e intención de compra. La formulación 4% BRS305 presentó más propiedades antioxidantes, pero menor aceptación sensorial que las otras formulaciones. No se observó diferencia significativa entre el control y el 2% BR501 para el color, sabor e impresión global, ni tampoco para textura e impresión global en relación al 4% BR501. El análisis de componente principal ha explicado que todas las variables asociadas a las propiedades antioxidantes han sido positivamente correlacionadas con el primer componente principal (PC1: 82,7%). Las formulaciones 2% y 4% BR501 se han correlacionado más con el PC1 (92,7%), así como el control con las características sensoriales. La adición de HIS BRS305 ha mejorado las propiedades antioxidantes de los yogurts y la adición de HIS BR501 no ha interferido en

Fernanda Cristina Esteves de Oliveira[1], Jovana Pontelo Pontes[2], Valéria Aparecida Vieira Queiroz[3], Elder Felipe Silva Roncheti[4], Victor Luiz Melo Dutra[5], Vinícius Tadeu da Veiga Correia[5], Andreza Angélica Ferreira[5].*

1. Centro Universitário Una, Sete Lagoas, MG, Brazil.
2. Department of Food Engineering, Universidade Federal de São João del Rei (UFSJ), Campus Sete Lagoas, Sete Lagoas, MG, Brazil.
3. Emprapa Milho e Sorgo, Sete Lagoas, MG, Brazil.
4. Instituto Federal do Pará (IFPA), Campus Marabá Rural
5. Department of Food, Faculty of Pharmacy, Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, MG, Brazil.

*Corresponding author: Andreza Angélica Ferreira
Department of Food, Faculty of Pharmacy,
Universidade Federal de Minas Gerais (UFMG),
Av. Presidente Antônio Carlos, 6627, 31270-901,
Pampulha, Belo Horizonte, MG, Brazil.
E-mail: andrezaferreira@ufmg.br

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la aceptación sensorial de las formulaciones. La similitud de la aceptación sensorial del yogurt que contiene el HIS del genotipo BR501 con el control, abre perspectivas para la inserción del sorgo en la alimentación humana, utilizando productos lácteos como matrices adecuadas, agregando funcionalidad potencial a este tipo de producto.
Palabras clave: Alimentos funcionales; Antocianinas; Lácteos; Sorghum bicolor L. Moench; Taninos.

INTRODUCTION

The fermented yogurt food matrix provides increased absorption and nutrient digestion and its consumption is associated with reduced risk of developing cardiovascular diseases and obesity[1]. Greek yogurt (GY), also known as Labneh, originated in the Balkans[2] and is usually fermented by the symbiotic lactic acid culture of *Streptococcus salivarius* subsp. *thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*, as well as traditional yogurt. GY is considered an intermediate product between fermented milk and fresh cheeses as the desorption of the curds after fermentation results in a concentrated product[2].

On average, GY contains between 20.5–24.6% total solids, 6.4-10.7% total fat, 8.2-10.4% total protein, 1.1-1.3% minerals and a pH range of 3.67–4.05, having on average: 2 to 3 times more fat and protein content, 50% more minerals and a higher number of viable microorganisms compared to traditional yogurts. GY has excellent creaminess, with little syneresis, is slight acidity around 1.80-2.00% and low lactose concentration (about 6.00%)[2]. The health benefits of yogurt may be even greater when paired with fruit or cereals rich in fiber and bioactive compounds[3].

The addition of fiber in yogurts can help to maintain the viability of probiotics in the product[4] by providing a substrate and conferring health benefits to hosts with constipation problems[5]. It is also known that whole grains present nutritional superiority due to the presence of embryo and bran grain structures which, besides fiber, contain: several minerals, vitamins and bioactive compounds. The consumption of whole grains is therefore recommended by nutritionists and other health professionals over the consumption of refined grains[6,7].

In this context, the incorporation of whole sorghum flour (WSF) (*Sorghum bicolor L.*) into GY may potentially result in a viable product alternative with functional properties.

Sorghum is a cereal that has significant concentrations of dietary fiber, minerals (iron, calcium, potassium) and vitamins (riboflavin, thiamine)[8,9]; in addition to bioactive compounds such as: phytosterols, policosanols, resistant starch, anthocyanins and condensed tannins[9,10]. Some of these compounds stand out for having a high antioxidant capacity, acting against the deleterious effects of free radicals in the organism[11,12,13]. Moreover, sorghum is gluten-free[13,14], making it a safe alternative for people with celiac disease and those with gluten intolerance[15,16,17].

However, it is known that some genotypes of this cereal may present differences in their chemical and nutritional composition[8,18], which can lead to technological and sensorial changes to the products to which they are added. Still, there are few studies that add sorghum to the milk matrix[16]; and none that compare the addition of different genotypes.

Thus, the aim of this study was to develop GY with added WSF of genotypes BRS305 (with tannin) and BR501 (tannin-free) and to evaluate antioxidant characteristics and sensorial acceptance.

MATERIAL AND METHODS

The experiment was carried out in laboratories of the Food Engineering Department of the Universidade Federal de São João del-Rei, (Sete Lagoas, Minas Gerais, Brazil) and at Embrapa Milho e Sorgo (Sete Lagoas, Minas Gerais, Brazil).

Whole sorghum flours (WSF) preparation

Two sorghum genotypes were selected based on their differences in pericarp color, chemical composition and bioactive compounds[8,10,19]. The BR 501 genotype has a white pericarp and no pigmented testa (tannin-free) and BRS 305 genotype has a brown pericarp and pigmented testa (with tannin). The preparation of WSF was carried out at Embrapa Milho e Sorgo with the following steps: 1) Manual selection of grains; 2) Sieving to remove dirt and impurities; 3) Milling in Hawos Mill, IKA model A11 Basic, for granulometry 0.5 mm; 4) Packing in polyethylene plastic bags, protected from the light; 5) Storage under refrigeration (4 °C) until GY processing and chemical analysis.

The proximate composition were performed, in triplicate, on WSF, according to AOAC[20] and the lipid content followed the AOCS protocol[21]. Neutral Detergent Fiber (NDF) was analyzed in 0.500 g of sample with a Tecnal EQ LCC 08 fiber analyzer using the Ankom system with filter bags[22].

Greek yogurt (GY) processing

The ingredients for GY processing (pasteurized whole milk, skimmed milk powder, crystal sugar and lactic yeast) were purchased at local market in Sete Lagoas, MG, Brazil. The lactic yeast (Docina Nutrição LTDA) contained the thermophilic cultures *S. thermophilus* and *L. bulgaricus*.

Five formulations of GY were developed: 1) Control (without addition of WSF); 2) 2% WSF from BR 501 genotype; 3) 4% WSF from BR 501 genotype; 4) 2% WSF from BRS 305 genotype and, 5) 4% WSF from BRS 305 genotype. The formulations were developed according to figure 1. The WSF concentrations were based on previous tests that subjectively evaluated the influence of different incorporation percentages on the yogurt texture. Texture is reported as one of the primary factors that determine the quality and acceptability of yogurt in the consumer market[23].

Antioxidant properties: total anthocyanins (TA), total phenols (TP), condensed tannins (CT) and antioxidant capacity (AC)

The analyses were performed at the Embrapa Milho e Sorgo Food Safety Laboratory, in three replicates and

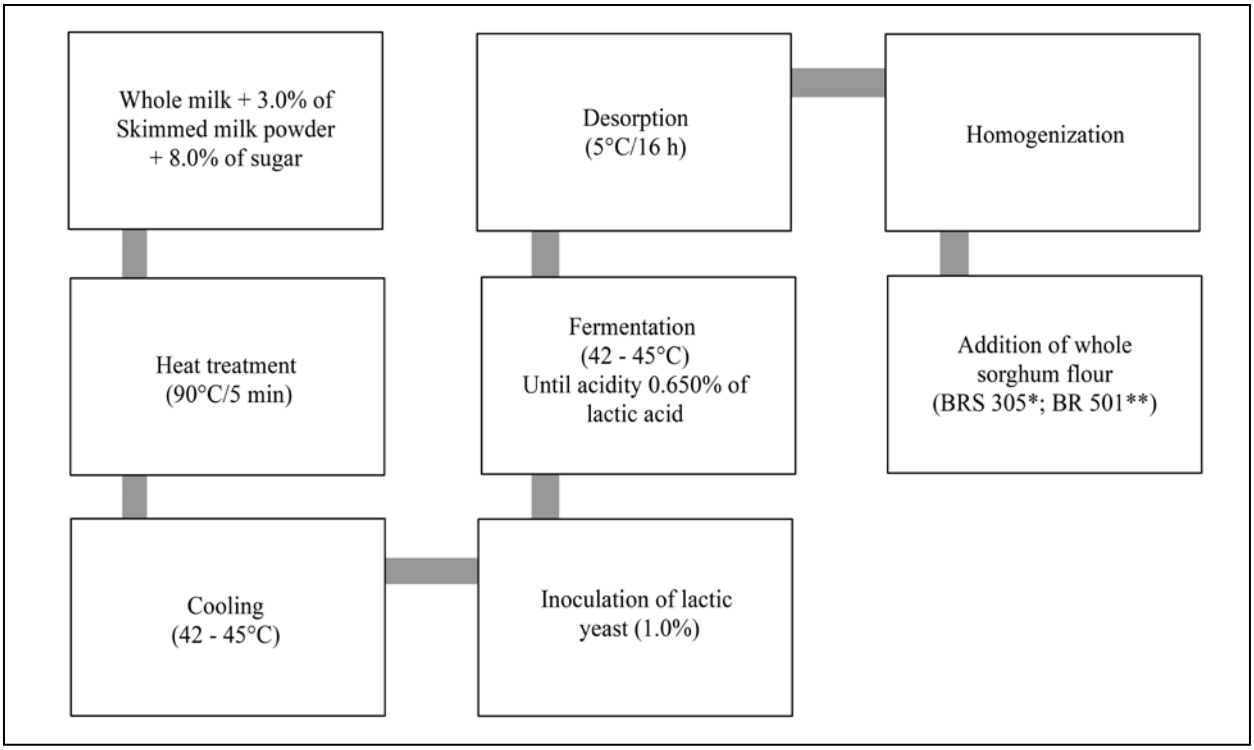

Figure 1: Greek yogurt with added whole sorghum flour processing steps.

*Whole sorghum flour of BRS 305: moisture 11.2%; ash 2.86%; protein 13.0%; fat 3.60%; carbohydrate 60.3%; fiber (FDN) 20.2%; 0.260 mg equivalent luteolinidine/g; 57.1 mg equivalent of catechin/g sample; 19.7 (mg gallic acid equivalents/g); 186.7 (mmol Trolox equivalent/g); 1.20 mg.100g^{-1} iron; 179.6 mg. 100g^{-1} phosphorus; 85.6 mg.100g^{-1} magnesium and 1.43 mg.100g^{-1} zinc.
**Whole sorghum flour of BR 501: moisture 10.4%; ash 4.20%; protein 13.4%; fat 4.58%; carbohydrate 65.1%; fiber (FDN) 12.7%; 0.080 mg equivalent luteolinidine/g; 0.090 mg equivalent of catechin/g sample; 3.92 (mg gallic acid equivalents/g); 3.90 (mmol Trolox equivalent/g); 1.28 mg.100g^{-1} iron; 250.3 mg.100g^{-1} phosphorus 123.3 mg.100g^{-1} magnesium and 1.85 mg.100g^{-1} zinc.

in triplicate. The AC and the concentrations of TA, TP and CT were determined using an absorbance of 734 nm[24], 480 nm, 600 nm and 500 nm, respectively[25,26] in a spectrophotometer (Instrutherm® Model UV-2000 A).

The AC was determined by the ABTS assay (2,2-azinobis-[3-etil-benzotiazoline-6-sulfonate] radical cation (ABTS)) according to the method presented by Awika et al.[24]. The results were expressed as µmol Trolox.g^{-1}, on a dry basis (db).

The method used for TA determination was that described by Fuleki & Francis[25], and further detailed by Awika & Rooney[27]. The concentrations of 3-deoxiantocianinas were calculated based on the absorbance of luteolinidin (480 nm) using the eq. C (mol/L)= A/ε, where C is sample concentration, A is the absorbance and ε is the molar extinction coefficient of luteolinidin. The molar extinction coefficient of luteolinidin used was 29.157 (Njongmeta, 2009). The results were expressed as mg luteolinidin equivalentes (LE)/g sample, on dry basis (db).

The TP was determined according to the method proposed by Kaluza et al.[28] and further detailed by Dykes et al.[29], using Folin Ciocalteau reagent. The results were calculated and expressed as mg gallic acid equivalent (GAE)/g sample, on a dry basis (db).

For CT determination, the Vanillin/HCl reaction method described by Price et al.[30] was used. The results were calculated and expressed as mg catechin equivalent (CE)/g sample, on a dry basis (db).

Sensory acceptance

The sensory tests to evaluate the acceptance of the GY with added tannin (BRS 305) and tannin-free (BR 501) WSF were carried out in the Sensory Analysis Laboratory of the Federal University of São João del Rei, (Sete Lagoas, Minas Gerais, Brazil). A total of 100 non-trained consumers, between 18 and 63 years of age, evaluated the sensory acceptability of the products.

The acceptance tests were performed in individual booths, where the non-trained consumers received instructions about the tests. They were requested to sign an Informed Consent Form, according to the Guidelines and Norms for Research with Humans, Resolution 466/2012 of the Brazilian National Health Council[31]. This study was approved by the

Human Ethics Research Committee at Federal University of Minas Gerais, Brazil (CAAE: 12457419.0.0000.5149).

The GY samples were served in 50 mL white plastic cups coded with three-digit numbers, in complete blocks, in a monadic, sequential and random order, in a single test session. Each consumer evaluated the attributes for: color, aroma, flavor, texture, and overall acceptability, using a 9-point hedonic scale (9= extremely like, 1= extremely dislike). The purchase intention was also evaluated using a 5-point scale (5= certainly would buy the product, 1= certainly would not buy the product).

Additionally, the acceptance index (AI) was calculated for each sensory attribute according to the formula[32].

$$AI\ (\%) = A \times 100 / B$$

Where, AI= acceptance index

A= acceptance test results average

B= highest score obtained in the acceptance test

The AI was classified into three groups[16]: (1) rejection <50.0%; (2) indifference between 50 and 59.0%; (3) acceptance ≥ 60.0%. The results were expressed in relative frequency.

Statistical Analyses

Data were analyzed using the software R version 3.5.3. The results were compared by analysis of variance (ANOVA), considering $p<0.05$ as significant. The Tukey test was used to determine significant differences among formulations ($p< 0.05$). Results were expressed as mean ± standard deviation. The AI data were analyzed by analysis of the relative frequency distribution.

The principal component analysis (PCA) was performed to evaluate the correlations of the addition of sorghum genotypes to the antioxidant and sensory variables of the formulations. Strong correlations were considered between 0.700-1.00[33].

RESULTS

Antioxidant properties: total anthocyanins (TA), total phenols (TP), condensed tannins (CT) and antioxidant capacity (AC)

Table 1 shows the AC and the TA, TP and CT concentrations for the GY formulations developed in this study.

The 4% BRS 305 formulation presented higher AC and higher TA, TP, CT contents when compared to the others ($p< 0.05$).

The TA content differed among all formulations ($p<0.05$, Table 1), with higher scores for those with added WSF from the BRS 305 genotype. Only the 2% BR 501 formulation did not differ from the control ($p> 0.05$) in relation to TA concentration, both presenting the lowest values when compared to the others.

Sensory acceptance

The sensory acceptance and purchase intention for the GY formulations are shown in table 2.

The control formulation obtained the highest mean scores for all sensory attributes and for purchase intent. However, there was no difference observed among the control formulation and the 2% BR 501 and 4% BR 501 formulations for the color and overall acceptability attributes. The control formulation also did not differ from the 2% BR 501 for flavor and 4% BR 501 for texture ($p> 0.05$, Table 2).

The mean scores for flavor of all the formulations are situated between the "I liked it" and "indifferent" hedonic terms, with AI, varying between 80.2% (control) and 60.3% (4% BRS 305).

On the other hand, the 4% BRS 305 formulation differed from the others in all sensory attributes evaluated ($p<0.05$), except for aroma ($p> 0.05$), presenting the lowest acceptance mean scores. The 2% BRS 305 formulation differed from the control for color and texture ($p<0.05$).

For the texture attribute, the control formulation and the 4% BR 501 formulation were the most accepted, with AI of 84.1% and 78.2%, respectively. On the other hand, the formulations with the WSF from the BRS 305 genotype obtained the lowest AI, 74.6% (2% BRS 305) and 63.1% (4% BRS 305).

Regarding overall acceptability, average scores were between the terms "I liked it very much" and "I liked it slightly", with AI varying between 83.8% (control) and 68.7% (4% BRS 305). The yogurts with added WSF from the BR 501 genotype were the most accepted, with AI of 79.8% (2% BR 501) and 77.9% (4% BR 501). The 4% BRS 305 formulation was the least accepted (AI= 68.7%). The formulations with lower concentrations of either WSF genotypes did not differ in relation to the overall acceptability attribute when compared to the control ($p> 0.05$).

Considering the purchase intention, only the 4% BRS 305 formulation was included in the "would not buy" range, differing from the others that were between the intentions "possibly would buy" and "maybe would buy." This result confirms their lower acceptance (Table 2). The 2% BRS 305 formulation did not differ in the intention to buy rankings when compared to the formulations with the WSF from the BR 501 genotype ($p> 0.05$), as their results were ranked between the terms "possibly buy" and "maybe buy".

Principal Component Analysis (PCA)

Figure 2 shows the PCA for the antioxidant characteristics and sensorial attributes of Greek yogurt.

Two principal components (PC1 and PC2) were used and together they explained 91.3% of the total variance of the antioxidant characteristics of the formulations; PC1 explained most of the variations (82.7%), all variables being positively correlated with PC1 (Figure 2B). The 4% BRS 305 formulation was characterized by a higher antioxidant content, while the other formulations presented similar antioxidant characteristics (Figure 2A).

Regarding sensory acceptance, the PCA showed that a principal component (PC1) explained 92.7% of the data

Table 1. Antioxidant capacity and concentrations of total anthocyanins, total phenolics and condensed tannins in Greek yogurt formulations.

Formulations	Antioxidant capacity (mmol TE/g)	Total anthocyanins (mg LUT/g)	Total phenolics (mg GAE/g)	Condensed tannins (mg CE/g)
Control[1]	15.9 ± 2.48[b]	0.012 ± 0.001[d]	3.65 ± 0.230[b]	0.203 ± 0.167[c]
2% BR 501[2]	18.7 ± 0.90[b]	0.016 ± 0.002[d]	3.62 ± 0.330[b]	0.115 ± 0.080[c]
4% BR 501[3]	18.8 ± 1.33[b]	0.027 ± 0.003[c]	3.23 ± 0.180[b]	0.457 ± 0.051[b]
2% BRS 305[4]	15.6 ± 1.16[b]	0.075 ± 0.005[b]	3.44 ± 0.400[b]	0.787 ± 0.260[b]
4% BRS 305[5]	36.3 ± 2.34[a]	0.109 ± 0.004[a]	5.06± 0.640[a]	2.50 ±0.330[a]

1. Greek yogurt without addition of whole sorghum flour (WSF); 2.2% WSF of BR 501 genotype; 3.4% WSF of BR 501 genotype; 4.2% WSF of BRS 305 genotype; 5.4% WSF of BRS 305 genotype. Means followed by the same letter in the same column are not significantly different by the Tukey test (P< 0.05).

Table 2. Sensory acceptance and intent to purchase Greek yogurt formulations.

Formulations	Color	Aroma	Flavor	Texture	Overall acceptability	Purchase intention
Control[1]	7.56 ± 1.27[a]	7.32 ± 1.35[a]	7.22 ± 1.42[a]	7.57 ± 1.42[a]	7.54 ± 1.24[a]	3.98 ± 1.10[a]
2% BR 501[2]	7.34 ± 1.36[ab]	6.76 ± 1.56[b]	6.90 ± 1.55[ab]	6.90 ± 1.49[b]	7.18 ± 1.26[ab]	3.55 ± 1.04[b]
4% BR 501[3]	7.25 ± 1.39[ab]	6.70 ± 1.43[b]	6.33 ± 1.64[b]	7.04 ± 1.50[ab]	7.01 ± 1.44[ab]	3.23 ± 1.14[b]
2% BRS 305[4]	7.05 ± 1.24[b]	6.90 ± 1.47[ab]	6.69 ± 1.64[ab]	6.71 ± 1.69[b]	7.00 ± 1.46[b]	3.39 ± 1.03[b]
4% BRS 305[5]	6.49 ± 1.49[c]	6.50 ± 1.65[b]	5.43 ± 1.95[c]	5.68 ± 2.00[c]	6.18 ± 1.65[c]	2.69 ± 1.15[c]

1. Greek yogurt without addition of whole sorghum flour (WSF); 2. 2% WSF of BR 501 genotype; 3.4% WSF of BR 501 genotype; 4.2% WSF of BRS 305 genotype; 5.4% WSF of BRS 305 genotype. Means followed by the same letter in the same column not are significantly different by the Tukey test (P< 0.05).

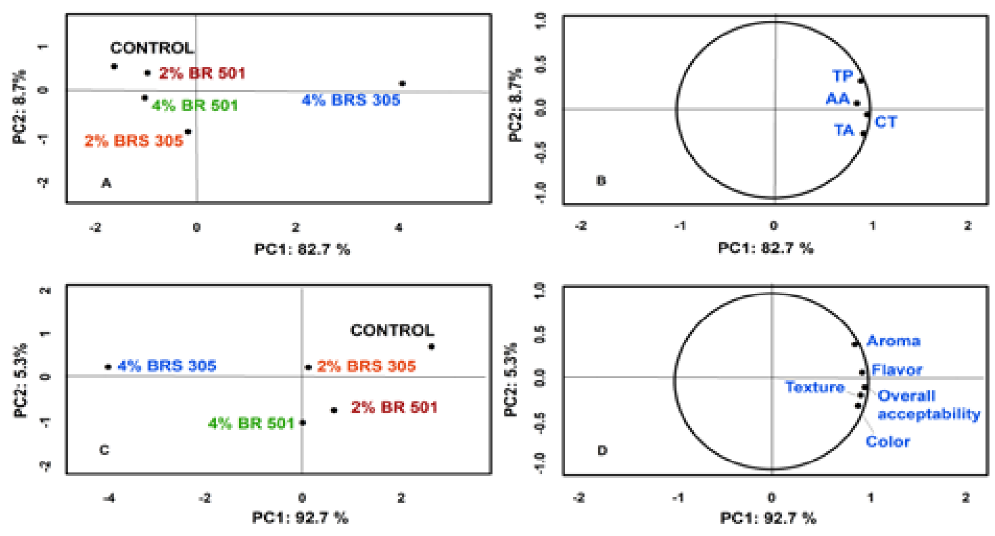

Figure 2: Scores (A and B) and loadings (B and D) plots of PCA for the antioxidants characteristics and sensorial attributes of Greek yogurt. Control: Greek yogurt without addition of whole sorghum flour (WSF); 2% BR 501: WSF of BR 501 genotype; 4% BR 501: 4% WSF of BR 501 genotype; 2% BRS 305: 2% WSF of BRS 305 genotype; 4% BRS 305: 4% WSF of BRS 305 genotype.

variance, and all attributes showed a strong correlation with the PC1 (Figure 2D). Thus, it was possible to use it in isolation to discriminate the samples.

Figure 2C shows that the control had a higher correlation with PC1, which was expected, since it obtained the highest averages in all the sensorial attributes evaluated (Table 2). On the other hand, the 2% BR 501 formulation were also strongly correlated with PC1.

DISCUSSION

The BRS 305 sorghum genotype has higher CT concentrations naturally[19]. Dykes et al.[29] and Wu et al.[34] reported that tannins have been identified as the main compounds that contribute to the increase of AC and TP in some sorghum genotypes. This explains the higher antioxidant properties presented in the GY formulations developed with sorghum genotypes in this study.

This genotype has brown pericarp and pigmented testa, which can result in alterations of color and flavor in the products to which it is added. Tannins are known to present an astringent and bitter residual flavor, which may compromise the palatability and product acceptance[27,35]. Therefore, the lower sensorial acceptance presented by the 4% BRS 305 formulation can be explained by the higher CT concentration found in this formulation (Table 1).

Queiroz et al.[16] developed a powder mixture for the preparation of beverages added with 56.7% of extruded sorghum flour, where the formulation containing tannin sorghum of the PDT-3670 genotype was more sensorially accepted for the attributes of flavor and overall acceptability than that containing tannin-free sorghum flour of the PDTF-7064 genotype.

These authors suggest that not all sorghum tannins negatively affect consumer acceptance and that other factors may also influence the acceptance of sorghum-added products such as grain processing (raw or extruded flour) and other ingredients which are present in the formulation of the product. The presence of polysaccharides, such as xanthan gums, for example, can react with tannins and reduce the sensation of astringency, leaving the product more palatable[16]. In addition, depending on the type of preparation, the condensed tannins may influence, to a greater or lesser degree, the sensory aspects of the product. In the present work, GY was formulated with non-extruded whole meal and may have undergone a greater negative influence of the addition of sorghum flour with tannins (BRS 305) than the beverage produced with extruded sorghum flour elaborated by Queiroz et al.[16].

Additionally, Queiroz et al.[16] verified that the AC, TA, TP and CT concentrations were higher in a powdered beverage made with 56.7% of extruded sorghum flour containing tannin from the PDT-3670 genotype. This suggests a greater functional potential compared to the added formulation of sorghum without tannin.

It stands out that, although the indication that the presence of tannins in foods reduces protein digestibility and food efficiency in humans and animals[36], the benefits of eating diets rich in tannins has highlighted because of an association with immunomodulatory, anticancer, antioxidant, anti-inflammatory, cardioprotective, vasodilator, and antithrombotic effects[11,36,37]. Thus, various research and a niche markets have emerged to capitalize on the benefits of sorghum with tannins through the development of products with higher concentrations of antioxidants and bioactive compounds[15,16,17,38,39,40,41].

It is known that anthocyanins, besides being bioactive compounds with antioxidant, cardioprotective, anticancer, anti-obesity, anti-inflammatory, anti-diabetic and antimicrobial properties, are red, purple and blue pigments that can be used as natural food colorants, in the form of extract, or even by adding their food sources[42].

Hernandez-Rodas et al.[43] reported the promising effect of some polyphenols, including anthocyanins in the prevention and treatment of nonalcoholic hepatic steatosis and its complications. These authors have described some mechanisms for reducing hepatocellular lipid accumulation and its deleterious effects on the organism: 1) inhibition of lipogenesis by decreasing SREBP-1c; 2) stimulation of lipolysis by inducing activity of PPAR-α and 3) reduction of oxidative stress. In association with anthocyanins and other phenolic compounds, the inclusion of sorghum in dairy matrices may enhance the benefits to human health by the presence of other natural antioxidants such as vitamin E, zinc and other compounds such as fiber and resistant starch.

Considering that the formulation 4% BR 501 presented higher concentrations of TA than the control formulation ($p<0.05$, Table 1), it is therefore suggested that the development of dairy products with added WSF constitutes a differentiated option for insertion into the market as these products are nutritionally richer and well accepted, regardless of the genotype of sorghum used.

For the texture attribute, the control formulation and the 4% BR 501 formulation were the most accepted. These formulations showed greater firmness, which probably affected the consumers perception for texture and palatability. Texture is reported as one of the primary factors that determine the quality and acceptability of this type of product in the consumer market[23]. The BR 501 genotype endosperm is more vitreous with firmer grain texture, resulting in a thicker flour, which may have influenced the development of a firmer textured product; whereas that the genotype BRS 305 presents smaller and softer grains, with more farinaceous endosperm, resulting in products with a softer texture[8,19,41,44].

Curti et al.[45] and Hasani et al.[4] added, respectively, quinoa flour at concentrations of 1.0%, 3.0% and 5.0% and barley bran at concentrations of 0.300%, 0.600%, 0.900% and 1.20% in yogurts and verified that higher cereal concentrations can affect texture as well as influence flavor and aroma, and thus contribute to product rejection. In general, the addition of cereals in yogurts causes a sandy texture, influenced by the type of cereal and its concentration[3,46]. However, in the present work, there was a greater influence of the sorghum genotype rather than that of the added concentrations.

In relation to overall acceptability, the results suggest that the addition of 2.0% of sorghum flour, independent of the genotype, did not significantly alter the majority of the sensorial characteristics of the GY, therefore this concentration of WSF may be indicated for continued studies involving the addition of sorghum in dairy products. Although the 4% BRS 305 formulation presented the lowest overall acceptability, the AI (68.7%) of this formulation was compatible with a percentage of acceptance proposed by Queiroz et al.[16] where preparations with AI≥ 60.0% are considered acceptable.

According to Curti et al.[45], overall acceptability is a complex term that comprises the combination of different sensory perceptions. In this context, the rejection by the consumer of any of the sensorial characteristics can negatively influence the general perception of the yogurt.

According to Prado et al.[41] the use of PCA provides a basis for determining patterns or data structure, as well as identifying the importance of individual variables in studies, thus facilitating the understanding of the dataset.

The results of the PCA in this study can be explained by the higher amount of WSF from the BRS 305 genotype added to the 4% BRS 305 formulation, associated with the antioxidant characteristics of this WSF with a higher CT and TA content (Table 1).

The 2% BR 501 formulation has the most similar characteristics to those of the control, confirmed by the results shown by the PCA (Figure 2) and therefore, from the point of view of the sensorial acceptance, would be the most adequate for industrial production.

Therefore, when evaluating GY formulations in a holistic manner, the addition of 4% WSF from the BRS 305 genotype was superior to the other formulations in relation to the antioxidant characteristics. However, in relation to the sensorial attributes, this WSF genotype negatively influenced the scores given by consumers, as well as their intention to purchase this product; while the GY formulations with the addition of WSF from the BR 501 genotype were closer to the sensory characteristics of the control formulation. Still the 4% BR 501 formulation presented higher content of anthocyanins than the control formulation, which indicates perspectives for the development of dairy products added with WSF with potential functionality.

According to Fernandez et al.[1], the chemical composition of yogurt associated with its fermented matrix can provide benefits with respect to the control of cardiometabolic diseases. The matrix effect of a food goes beyond individual nutrients, suggesting that the physical structure created by a combination of nutritional components, can act independently of its individual components during digestion and metabolism[1]. Furthermore, Lamothe et al.[47] reported that the dairy matrix structure can assist in maintaining and integrity of the antioxidant activity of polyphenols present in beverages such as green tea during digestion. Additionally, the incorporation of fiber-rich whole grains may have additional effects on yogurt functionality[6]; thus, the addition of sorghum in yogurt represents the possibility of developing differentiated products. These products have more fiber, mainly insoluble fiber, more bioactive compounds such as condensed tannins and anthocyanins, vitamin E and various minerals such as iron, phosphorus, magnesium and zinc[8]. Thus, in addition to the benefits usually associated with yogurt, it can contribute to a healthier diet, allowing improved traffic and intestinal health and preventing cardiovascular disease, cancer, obesity, high blood pressure, diabetes mellitus, hepatic steatosis, among others.

CONCLUSION

This work represents the first scientific approach of the incorporation of whole sorghum flour from different genotypes into Greek yogurt on the antioxidant and sensorial properties. The addition of these whole flours, especially the BRS 305 genotype, improved the antioxidant properties of the formulations developed. However, specific characteristics of this genotype, such as a higher concentration of condensed tannins, probably negatively influenced the sensory acceptance and purchase intention of these formulations. On the other hand, the similarity of the sensory acceptance of the yogurt containing the WSF from the BR 501 genotype to the control, opens perspectives for the insertion of sorghum in human food, using dairy products as suitable matrices, adding potential functionality to this type of product. Therefore, more studies are suggested to better investigate the technological advantages of the incorporation of sorghum into fermented dairy products, adjusting flour concentrations to balance the nutritional quality and the sensorial aspects of the products.

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