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FOOD TECHNOLOGY

Application of lyophilized purple-fleshed sweet potato powder as a multifunctional ingredient in Greek yogurt

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ABSTRACT: Purple-fleshed sweet potato is a tuber rich in anthocyanins, which are phenolic pigments that confer color and present bioactive capacity. Moreover, its incorporation into dairy products can bring technological and functional benefits. Thus, this article evaluated the impact of the addition of lyophilized purple-fleshed sweet potato powder - LP (0% - Control, 2%, and 4%) on the physical, chemical, and technological characteristics of Greek yogurt. LP showed *in vitro* antioxidant and bioactive capacity by DPPH (20.64 ± 1.61 µmol TE g^{-1}), FRAP (112.93 ± 4.38 µmol TE g^{-1}), total phenolic content (103.66 ± 3.35 mg GAE g^{-1}), and total anthocyanin content (51.10 ± 1.87 mg cyanidin 3-glucoside 100 g^{-1}). Additionally, the assays demonstrated that the LP has 16.82 ± 0.63% of resistant starch. The fortification of Greek yogurt with LP reduced the syneresis, indicating that LP increased the water retention capacity. LP also inhibited the post-acidification process, increasing apparent viscosity, hardness, and gumminess, and promoting a stable pink coloration throughout the storage ($P < 0.05$). At the 4% level, the yogurt was firmer and showed greater chewiness, which is highly desirable for Greek yogurt. Therefore, the results suggested that lyophilized purple-fleshed sweet potato powder is a potential multifunctional natural ingredient.
Key words: anthocyanins, clean label, Beni imo, natural food coloring, natural food ingredient.

Aplicação de pó liofilizado de batata-doce de polpa roxa como ingrediente multifuncional em iogurte tipo Grego

RESUMO: Batata-doce de polpa roxa é um tubérculo rico em antocianinas, as quais são pigmentos fenólicos que conferem cor e apresentam capacidade bioativa. Além disso, sua incorporação em produtos lácteos pode trazer benefícios tecnológicos e funcionais. Desta forma, este estudo teve como objetivo avaliar o impacto da adição de pó liofilizado de batata-doce de polpa roxa – LP (0% - Controle, 2% e 4%) nas características físicas, químicas e tecnológicas de iogurte tipo Grego. LP apresentou capacidade antioxidante e bioativa *in vitro* para DPPH (20.64 ± 1.61 µmol TE g^{-1}), FRAP (112.93 ± 4.38 µmol TE g^{-1}), teor de compostos fenólicos totais (103.66 ± 3.35 mg GAE g^{-1}) e teor de antocianinas totais (51.10 ± 1.87 mg cyanidin 3-glucoside 100 g^{-1}). Adicionalmente, os ensaios demonstraram que o LP possui 16,82 ± 0,63% de amido resistente. A fortificação do iogurte Grego com LP reduziu a sinérese, indicando que LP aumentou a capacidade de retenção de água, LP também inibiu o processo pós-acidificação, aumentando a viscosidade aparente, a dureza e a gomosidade, e promovendo uma coloração rosa estável durante todo o armazenamento ($P < 0,05$). No nível de 4%, o iogurte apresentou-se mais firme e com maior mastigabilidade, o que é altamente desejável para o iogurte tipo Grego. Assim, os resultados sugerem que o pó liofilizado de batata-doce de polpa roxa é um potencial ingrediente natural multifuncional.
Palavras-chave: antocianinas, clean label, Beni imo, corante alimentício natural, ingrediente alimentício natural.

INTRODUCTION

Eating habits have changed considerably in recent years. There is a growing demand for products with a closer approach to healthiness, due to increased awareness about food health, which directly interfere with purchase and consumption intentions (HSU et al., 2023). The food choice is often conditioned to less processed foods and ingredients that do not cause harm to human health in the short, medium, and long term (ASCHEMANN-WITZEL, 2015). The clean label movement is one of the trends that has promoted the modification of the composition of processed foods, stimulating the use of ingredients that can be easily identified by consumers by considering the reduction and/or elimination of non-natural ingredients and/or non-renewable sources (ASIOLI et al., 2017; ASCHEMANN-WITZEL et al., 2019).

Studies on the research and development of multifunctional and natural ingredients have been performed presenting a promising strategy to support the supply of products that meet consumers' demands (GRANATO et al., 2017). Vegetable matrices have been the object of study for obtaining such ingredients, since they are obtained in a renewable way (KIM et al., 2020). For a vegetable to be considered a viable

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source of natural additives, it should satisfy some criteria, such as: good availability, low price, and high yield (STINTZING & CARLE, 2004). These criteria make possible to explore several sources other than conventional ones for obtaining natural ingredients, such as purple-fleshed sweet potato (PFSP).

PFSP growth is easily managed and can be cultivated in regions with different climatic conditions and low fertility soils (TANAKA et al., 2017). Because of its high amounts of anthocyanins and phenolic compounds, this tuber has been gaining space among consumers. The bioactive compounds present in PFSP are associated with reduced risks and incidence of degenerative diseases (LIM et al., 2013). Anthocyanins from PFSP are more stable to heat and UV-light irradiation (TSUKUI et al., 1999). In addition, it is a tuber rich in starch - total and resistant (JI et al., 2015).

Regarding its functionalities, PFSP is a promising alternative for the development of functional ingredients, capable of conferring desirable bioactive, physical, and chemical characteristics such as color enhancement, antioxidant capacity improvement, increase in water retention capacity, and reduction in the glycemic response (ZHU & SUN, 2019; SUDJATINAH et al., 2020). It can be used in varied products, such a Greek yogurt, which is a dairy product obtained from the concentration of yogurt by drainage. Greek yogurt has high viscosity, high total solids content, and contains lactic acid bacteria (LAB) and their metabolites, making it a functional product (JRAD et al., 2019; DU et al., 2021).

Although, the application of purple-fleshed sweet potato as an ingredient is already a reality in bakery products, desserts, and snacks in the Asian market, the use of sweet potato powder as a food additive in dairy products is an innovation. Thus, this study evaluated the effects of supplementation of lyophilized purple-fleshed sweet potato powder (LP) on the physical, chemical, and technological characteristics of Greek yogurt.

MATERIALS AND METHODS

Material

Purple-fleshed sweet potato (PFSP) was obtained from the Agro Rei Rural Property, located in Seropédica, Rio de Janeiro, Brazil (22° 47' 03.6" South latitude and 43° 39' 40.1" West longitude). The variety used is called "Beni imo" Sweet Potato and has purple flesh and white skin. UHT whole milk – 3% of fat (Quatá®, São Paulo, Brazil), creamy milk cream – 20% of fat (Qualitá®, São Paulo, Brazil), and skimmed milk powder (Molico – Nestlé®, Sao Paulo, Brazil) were obtained from a local market (Rio de Janeiro, Brazil). Lyofast Y 438 A, a lyophilized culture of *Streptococcus thermophilus* and *Lactobacillus delbrueckii ssp bulgaricus,* was supplied by Sacco Brasil® (São Paulo, Brazil).

Heat treatment of PFSP and obtaining lyophilized purple-fleshed sweet potato powder (LP)

PFSP was manually harvested, selected, washed, and sanitized by immersion in a sodium hypochlorite solution (200 ppm for 15 minutes). Then, it was peeled and chopped into pieces of 5 cm².

PFSP was heat-treated by immersion in water at 80 °C for 10 minutes (ratio 1:3 w/w). After the heat treatment, the potatoes and the cooking water were processed in an industrial blender for 10 minutes. The puree obtained was placed in airtight plastic packaging and frozen at -18 °C in a conventional freezer for 7 days. Subsequently, the puree was lyophilized in a benchtop lyophilizer (Liotop®, model L101) for an average period of 5 days, crushed in an industrial blender, and selected in a 710 µm granulometric analysis sieve. This process resulted in the lyophilized purple-fleshed sweet potato powder (LP), which was stored in airtight containers under refrigeration (4 °C).

Production and enrichment of Greek yogurt with LP

Greek yogurt was produced in batch, following the procedures described by SANTOS et al. (2022) with adaptions. UHT whole milk was supplemented with skimmed milk powder in a proportion of 2% (w/w). The mixture was heated until 43 °C in a water bath and lyophilized culture of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp *bulgaricus* were added (0.07 g/L of milk), following the manufacturer's recommendation. Then, it was incubated in a water bath at 43 °C until reaching a pH value between 4.5 and 4.6.

After coagulation, the curd obtained was transferred to sterilized cotton bags for drainage, which was carried out under refrigeration at 4°C for 18 h. The whey was discarded, and the concentrated yogurt was supplemented with milk cream at a ratio of 10% (w/w). Then, the obtained yogurt was divided into three equal parts. Two parts were enriched with LP using two proportions [2% w/w (A_2) and 4% w/w (A_4)]. Thus, three different samples were obtained: Control (without LP), A_2, and A_4. The samples were fractionated in airtight plastic packages containing 30 g of yogurt each and stored under refrigeration (4 ± 1 °C). Figure 1 shows a general flowchart of the

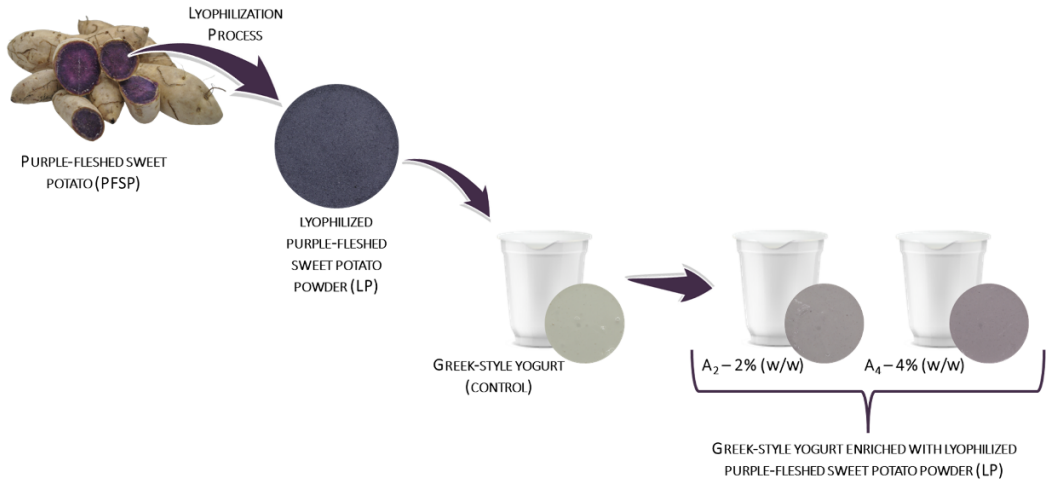

Figure 1 - General flowchart of the enrichment of Greek yogurt using lyophilized purple-fleshed sweet potato powder (LP).

enrichment of Greek yogurt using lyophilized purple-fleshed sweet potato powder (LP).

Chemical composition

The procedures described by IAL (2008), with minor adaptations, were performed to determine the chemical composition of PFSP and LP. Moisture was determined by the gravimetric method of desiccation with direct drying in a non-ventilated oven at 105 °C until constant weight – Protocol n° 012/IV (IAL, 2008). The total carbohydrates level was determined by the Somogyi-Nelson method, which is based on the reduction of copper by sugar reducing groups. A standard curve was used with anhydrous glucose concentrations ranging from 25 to 500 mg L^{-1} – Protocol n° 281/IV (IAL, 2008). Total dietary fiber was determined by the enzymatic-gravimetric method, from the defatted samples – Protocol n° 045/IV (IAL, 2008). Protein level was obtained by determining the total nitrogen content by the modified Kjeldahl method. The procedure was performed in 3 stages: digestion, distillation, and titration – Protocol n° 037/IV (IAL, 2008). Determination of lipids was carried out by extraction in Soxhlet using petroleum ether as hot solvent for an average period of 6 hours of continuous extraction – Protocol n° 032/IV (IAL, 2008). The ash level was quantified by the gravimetric method of incineration in muffle furnace at 550 °C until constant weight – Protocol n° 018/IV (IAL, 2008). Total starch (TS) content was determined by acid hydrolysis assisted with high temperatures in autoclave at 121 °C/1 atm – Protocol n° 043/IV (IAL, 2008).

In vitro digestibility of starch

The *in vitro* digestibility of starch of PFSP and LP was evaluated using the methods described by MA et al. (2021) and GONG et al. (2022), with slight modifications. PFSP was dried in a forced circulation oven at 40 °C. The sample (200 mg) was mixed with 15 mL of preheated phosphate buffer (37 °C; pH 5,60 – 5,80) and shaken at 37 °C for 5 minutes, followed by the addition of 5 mL of an enzymatic solution containing pancreatic α-amylase (290 U/mL) and amyloglucosidase (15 U/mL). The mixture (sample + enzymatic solution) was incubated at 37 °C under shaking conditions (100 rpm) for 3 h. At predetermined time points, 1.00 mL of hydrolysate was withdrawn, and the reaction was stopped using an ice bath. The glucose content was determined using the Somogyi-Nelson method – Protocol n° 281/IV (IAL, 2008), and the starch content was calculated by multiplying the glucose level by a factor of 0.90. The content of starch was classified in three types: rapidly digested starch – RDS (starch digested after 20 minutes), slowly digested starch – SDS (starch digested between 20 and 120 minutes), and resistant starch – RS (undigested after 120 minutes). The contents of RDS, SDS, and RS were determined based on Equations 01, 02, and 03:

$$RDS(\%) = \left(\frac{S_{20} - S_0}{TS}\right) \times 100 \quad (1)$$

$$SDS\ (\%) = \left(\frac{S_{120} - S_{20}}{TS}\right) \times 100 \quad (2)$$

$$RS\ (\%) = \left(\frac{TS - RDS - SDS}{TS}\right) \times 100 \quad (3)$$

Total anthocyanin content (TAC)

The TAC of LP and yogurt samples was determined using the procedure reported by DU et al. (2021), with modifications. The extracts were prepared with 1.5 g of samples and 30 mL of an acidified ethanolic aqueous solution (60% v/v) in an ultrasound bath for 2 h. The samples were centrifuged at 3,570 × g for 20 minutes at 4°C. The supernatants were filtered, and the TAC was determined using the pH differential method (pH 1.00 and pH 4.50) described by LEE et al. (2005).

An aliquot of 2.00 mL of the extract was added to 3.00 mL of a potassium chloride buffer solution (0.025 M/pH 1.00) and 3.00 mL of a sodium acetate buffer solution (0.4 M/pH 4.00). The mixture was homogenized and allowed to rest for 15 minutes. Then, absorbances were measured at 530 and 700 nm using a scanning spectrophotometer (Model WUV – M51, WEBLABORSP, Mogi das Cruzes, São Paulo, Brazil). The TAC was quantified according to Equations 04 and 05 and was expressed as mg cyanidin 3-glucoside 100 g^{-1}.

$$A = [(A_{520\ nm/pH\ 1.00} - A_{700\ nm/pH\ 1.00}) - (A_{520\ nm/pH\ 4.50} - A_{700\ nm/pH\ 4.50})] \quad (4)$$

$$TAC = \left(\frac{A}{\varepsilon \times L}\right) \times MM \times 100 \times f_d \quad (5)$$

In which: A is the absorbance corrected by the difference between the absorbances recorded in the readings at pH 1.00 and pH 4.50; ε is the molar extinction coefficient of anthocyanin; L is the length of the optical path (1 cm); MM is the molecular mass of anthocyanin; f_d is the dilution factor of the sample; TAC is the total anthocyanin content.

Antioxidant capacity (DPPH radical-scavenging assay and Ferric reducing antioxidant capacity – FRAP assay) and total phenolic content

The bioactive properties were determined using extracts prepared with an extracting solution of methanol 70%. For the PFSP extract, 2.0 g of sample were extracted with 20 mL of the methanolic solution, while 0.2 g of LP were used for the extract preparation. The DPPH radical-scavenging assay was based on the methodology described by RUFINO et al. (2010), with minor modifications. An aliquot of 150 µL of extract was added to 2.85 mL of a DPPH solution and allowed to react for 1 h. Then, the absorbance was read at 517 nm with a spectrophotometer. Trolox was used to construct a standard curve (from 5 to 70 µg mL^{-1}) and the DPPH value was expressed as µmol trolox equivalents per gram of sample (µmol TE g^{-1}). The antioxidant capacity determined by the ferric reducing antioxidant capacity – FRAP assay was based on the methodology reported by THAIPONG et al. (2006), in which trolox was also used as reference. The extract (90 µL) was added to 270 µL of distilled water and 2.7 mL of FRAP reagent [25 mL of 0.3 M acetate buffer; 2.5 mL of a 10 mM solution of TPTZ (2, 4, 6-tri(2-pyridyl)-1,3,5-triazine), and 2.5 mL of a 20 mM aqueous solution of ferric chloride]. The mixture was incubated at 37 °C under shaking for 30 minutes and cooled. The absorbance was read at 595 nm with a spectrophotometer and the FRAP value was expressed as µmol trolox equivalents per gram of sample (µmol TE g^{-1}). The total phenolic content was determined according to RUFINO et al. (2010), with minor modifications. An aliquot of 1 mL of the extract was added to 1 mL of the Folin-Ciocalteau aqueous solution (1:10), 1 mL of methanol 70%, and 1 mL of Na_2CO_3 aqueous solution (10% w/v). The mixture was allowed to rest for 2 h in the dark. The absorbance was read at 725 nm with a spectrophotometer. Gallic acid was used as reference to construct a standard curve (from 5 to 40 µg mL^{-1}) and the total phenolic content was expressed as mg gallic acid equivalents per gram of sample (mg GAE g^{-1}).

pH, titratable acidity, and color

Yogurt samples were analyzed at days 0, 10, 20 and 30. The pH value was measured using a digital potentiometer (Oharus Starter 2100, Canada). The titratable acidity was determined using a 0.1 M sodium hydroxide solution as titrant and a phenolphthalein ethanolic solution as an indicator, following the procedure indicated by IAL (2008). Yogurt samples were packed in glass plates and color was measured using a colorimeter Spectrophotometer CM – 5 (Konica Minolta®, Osaka, Japan). The parameters CIELab L^*, a^*, and b^* were determined, in which L^* value ranges from 0 (black) to 100 (white), coordinate a^* represents red (positive) to green (negative), and b^* represents yellow (positive) to blue (negative). The total color difference (ΔE) was calculated using the values of L^*, a^*, and b^*, according to Equation 06.

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (6)$$

Syneresis

Syneresis was measured using the procedure described by KIM et al. (2020), with modifications. The assay was performed with 3 simultaneous replications in single units of each sample. A system was assembled containing a plastic funnel with Whatman filter number 1 coupled to an

Erlenmeyer flask. Yogurt samples (20 g) were placed in the funnel and the entire system was kept under refrigeration (4 °C) for 30 days. To minimize and avoid exchanges with the environment, the system was protected with a thermoplastic film (Parafilm®). Expelled water was collected in an Erlenmeyer flask and weighed at 0, 10, 20, and 30 days of storage. The syneresis index was determined accorfing to Equation 07.

$$\text{Syneresis (\%)} = \left(\frac{\text{expelled water}}{\text{sample weight}}\right) \times 100 \quad (7)$$

Apparent viscosity and texture analysis

Apparent viscosity analysis of samples was carried out after a rest of 24 hours under refrigeration (4 °C) in a rotational concentric cylinder viscometer (model 35 A, Fann Instrument Company, Houston, EUA). To minimize interferences, the yogurt samples were transferred to metal cylinders and allowed to rest under refrigeration temperature (4 °C) for 30 minutes. The readings were performed in an air-conditioned environment and the samples were evaluated under the rotation velocities of 0.9, 1.8, 3, 6, 30, and 60 rpm. The experimental data obtained were shear rate and shear stress and the results were expressed by apparent viscosity in relation to the rotational speed.

The texture analysis of Greek yogurt was carried out in a TA – XT2 texture analyzer (Stable Micro Systems, Godalming, Surrey, UK). After packing, the samples were allowed to rest under refrigeration (4 °C) for 24 hours. The assay was performed with 3 simultaneous replications in single units of each sample. Each reading was conducted using approximately 30 g of yogurt, previously stored in airtight plastic packages. A cylindrical probe with 35 mm of diameter equipped with and a 5-kg load cell was used for Texture Profile Analyses. The analysis conditions were as follows. Pretest speed: 1.7 mm/s; test speed: 1.7 mm/s; posttest speed: 1.0 mm/s; 2 penetration cycles; distance traveled by the device in the sample: 5 mm; contact force: 100 g; contact time: 5 s. The parameters obtained were hardness, cohesiveness, adhesiveness, springiness, gumminess, and chewiness.

Statistical analysis

All experiments were performed in triplicate. Results were expressed as mean ± standard deviation. The data were analyzed by analysis of variance (ANOVA), the means were compared by the Tukey's test, and 5% significance level was considered ($P < 0.05$). The statistical analysis was performed using Statistic 10.0 (Stats oft®, Tulsa, USA).

RESULTS AND DISCUSSION

Chemical composition

Table 1 presents the macronutrient contents on a dry basis.

The contents determined for PFSP corroborate the findings of the scientific literature. JI et al. (2015) evaluated the chemical composition of different types of sweet potatoes and reported contents of 0.72% for lipids and 2.06% for ash in a variety of purple-fleshed sweet potatoes. However, the protein content reported by the authors was approximately three times higher (6.41% versus 2.07%), while LP presented a dietary fiber content approximately 8 times higher than the one obtained in this study (16.97% versus 2.35%). Samples of purple-fleshed sweet potato evaluated by LIM et al. (2013) presented contents similar to the ones quantified in this study: 1.5% for proteins, 0.20% for lipids, 15.8% for total dietary fiber, and 1.3% for ash.

Regarding the chemical composition of LP, the values found here are also in agreement with the scientific literature. According to ALBUQUERQUE et al. (2020), flours obtained from four sweet potato varieties showed contents varying from 2.1% to 2.3% for ash and from 1.8% to 3.6% for proteins, which were close to the levels reported in the present study. FITRI et al. (2023) and NGOMA et al. (2019) reported lipid contents of 0.76% and 0.69% for purple-fleshed sweet potato flours respectively, results close to that found for LP (0.68%). ISLAM et al. (2020) also studied

Table 1 - Chemical composition of purple-fleshed sweet potato (PFSP) and lyophilized purple-fleshed sweet potato powder (LP).

Sample	----------Results in dry base (%), except moisture----------					
	Moisture	Total carbohydrates and total starch	Dietary fiber	Protein	Lipid	Ash
PFSP	$66.69^{a} \pm 0.47$	$78.43^{a} \pm 3.86$, of which: $53.14^{a} \pm 1.57$	$16.97^{a} \pm 0.30$	$2.07^{b} \pm 0.10$	$0.84^{a} \pm 0.04$	$1.69^{b} \pm 0.04$
LP	$2.37^{b} \pm 0.12$	$78.58^{a} \pm 4.36$, of which: $53.27^{a} \pm 4.36$	$11.48^{b} \pm 0.58$	$3.97^{a} \pm 0.15$	$0.68^{b} \pm 0.04$	$2.92^{a} \pm 0.20$

[a–b] Different letters in the same column indicate significant differences ($P < 0.05$).

purple-fleshed sweet potato flour and determined a total dietary fiber content of 9.97%, similar to LP. Varied macronutrient contents observed in plants may be attributed to intrinsic, extrinsic, and environmental factors, such as genetic conditions and improvement, genotype/cultivar/variety, soil type, forms of cultivation, water availability, and management during and after harvest (FRACASSO et al., 2016).

Significant differences ($P < 0.05$) were observed by comparing the macronutrient contents of PFSP and LP, except for total carbohydrates, indicating that the process applied had a direct impact on the chemical composition of LP. Moreover, there was a reduction in the content of dietary fibers and lipids, while the levels of ash and proteins increased. It is known that freeze-drying is a unitary operation of great importance in food preservation. One of its main characteristics is the preservation of physical, chemical, nutritional, and bioactive characteristics of food (PANDITH et al., 2023). Thus, it indicated that such changes were due to the heat treatment applied prior to freeze-drying (80 °C for 10 minutes). Other authors have also reported variations in the chemical composition of sweet potatoes after heat processing. OGLIARI et al. (2020) observed changes in the macronutrient contents of sweet potatoes after boiling, which was also described by CHEONG et al. (2022).

Despite the changes in macronutrient contents (Table 1), it is possible to observe that both PFSP and LP had more than 10.00% of fibers and low lipid contents (less than 1.00%), in addition to considerable ash levels. Sweet potatoes are subsistence foods with remarkable nutritional quality, being a source of fiber (ZHU & SUN, 2019). Therefore, the fortification of foods using PFSP or LP, can be beneficial for the nutritional improvement of products.

In vitro digestibility of starch

PFSP and LP presented total starch (TS) and rapidly digested starch (RDS) values close to 53% and 75%, respectively (Table 2), with no significant differences ($P < 0.05$) between samples. However, significant variations were observed for the contents of slowly digested starch (SDS) and resistant starch (RS) (Table 2). Regarding the SDS, PFSP presented 21.54% (13.80% higher than LP), while PFSP presented 2.77% (14.02% lower than PFSP) for RS. KATAYAMA et al. (2011) evaluated the resistant starch content of 21 sweet potato cultivars and found results ranging from 1.8% to 9.5%, which is the same range of the value determined herein for PFSP. ZHENG et al. (2016) reported a RS level within this same range, but higher than PFSP (5.02%). Conversely, SUN et al. (2022) observed a RS content equal to 1.44% (lower than PFSP). As previously stated, the composition of vegetables may vary due to intrinsic and extrinsic factors (FRACASSO et al., 2016).

The equivalence of the differences observed between SDS and RS indicates that the starch hydrolysis in PFSP was anticipated, reducing the RS content after the *in vitro* digestive process. This finding suggested that the heat treatment applied to obtain LP improved the content of RS. According to HAGENIMANA et al. (1992), thermal processes can denature amylases naturally present in sweet potato roots, which reduces starch hydrolysis and promotes a debranching of the α-(1,6) bond of amylopectin that is converted into small-chain linear polysaccharides. ZHENG et al. (2016) evaluated the impact of heat treatment combined with moisture on the improvement of the prebiotic characteristics of purple-fleshed sweet potatoes and observed that the value of resistant starch almost tripled, increasing from 5.02% to 14.23%.

Although, carbohydrates are the main components of LP, part of this macronutrient is in the form of resistant starch, which presents a glycemic response inferior to other known carbohydrate sources (ZHU & SUN, 2019). The RS starch content of 16.82% for LP is highly advantageous as it allows

Table 2 - Values of total starch (TS), rapidly digested starch (RDS), slowly digested starch (SDS), and resistant starch (RS) of purple-fleshed sweet potato (PFSP) and lyophilized purple-fleshed sweet potato powder (LP) after simulation of in vitro digestibility.

Sample	----------Results in dry base (%), except moisture----------			
	TS	RDS*	SDS*	RS*
PFSP	$53.14^{a} \pm 1.57$	$75.35^{a} \pm 0.82$	$21.54^{a} \pm 0.91$	$2.77^{b} \pm 0.12$
LP	$53.27^{a} \pm 4.36$	$75.44^{a} \pm 1.25$	$7.74^{b} \pm 0.67$	$16.82^{a} \pm 0.63$

$^{a–b}$ Different letters in the same column indicate significant differences ($P < 0.05$); *Values in relation to total content of starch (TS) in dry base (%).

its incorporation into food as a functional ingredient. It may be due to both the resistant starch content and the potential as a fiber source, since a considerable part of the carbohydrates of this matrix reaches the large intestine without being hydrolyzed, where it is fermented by colonic bacteria and can have prebiotic effects (GIBSON et al., 2017). ZHU & SUN (2019) studied the supplementation of bread with purple-fleshed sweet potato flour and observed that the addition of different levels reduced the quickly and slowly digested starch and increased the resistant starch content. In addition, the authors noticed that the higher the supplementation with sweet potato flour, the lower the glycemic response, indicating that the starch had greater resistance to *in vitro* digestion, reducing the release of hydrolyzed sugars.

Total anthocyanin content, antioxidant capacity (DPPH radical-scavenging assay and Ferric reducing antioxidant capacity – FRAP assay), and total phenolic content

The presence of natural antioxidant compounds can promote the prevention of non-chronic disorders, as well as inhibit the activity of free radicals associated with oxidative processes of lipids, proteins, RNA, DNA, and sugars, which can lead to the incidence of pathologies such as cancer, Alzheimer's and Parkinson's diseases, autoimmune deficiency, and degenerative disorders like diabetes and obesity (HU et al., 2016). Purple-fleshed sweet potato is a known source of bioactive compounds with anti-inflammatory and anticancer activities (SUGATA et al., 2015). It presents antihyperglycemic properties due to the inhibition of the enzyme α-glucosidase (MATSUI et al., 2002), as well as antiatherosclerotic (MIYAZAKI et al., 2008) and antihypertensive effects (KOBAYASHI et al., 2005). Table 3 brings the results obtained for total phenolic content (TPC), antioxidant capacity (DPPH and FRAP), and total anthocyanin content (TAC) of PFSP, LP, and yogurt samples (control, A_2, and A_4).

The values of TPC, DPPH, and FRAP were significantly different ($P < 0.05$) for PFSP and LP. An increase in LP was observed for these parameters (Table 3). For TPC, the results found in the present study were higher than those reported by JI et al. (2015), who described a content of 54.3 mg GAE g^{-1} for purple-fleshed sweet potatoes. However, the authors obtained a considerably higher response for DPPH, once they observed a value of 81.2 µmol TE g^{-1}, while PFSP presented a content of 16.50 µmol TE g^{-1}. LIM et al. (2013) reported similar results, with a lower content for TPC (16.10 mg GAE g^{-1}), but for FRAP, the authors had better performance (337.21 versus 50.40 µmol TE g^{-1}).

PFSP and LP showed no significant differences ($P < 0.05$) regarding the TAC (Table 3). The levels found were 54.59 mg cyanidin 3-glucoside 100 g^{-1} for PFSP and 51.10 mg cyanidin 3-glucoside 100 g^{-1} for LP, respectively. There is a great variation in the values described in the scientific literature for anthocyanin contents. HU et al. (2016) studied the anthocyanin contents of 30 varieties of purple-fleshed sweet potatoes and reported values ranging from 74.3 to 607 mg cyanidin 3-glucoside 100 g^{-1}. ISLAM et al. (2020) found a total anthocyanin concentration of 59.92 mg cyanidin 3-glucoside 100 g^{-1} for purple-fleshed sweet potato flour, which is similar to the one determined in the present study for LP (51.10 mg cyanidin 3-glucoside 100 g^{-1}). Variations in bioactive contents are already expected. According to ISLAM et al. (2020), the levels of anthocyanins and other bioactive components can be influenced by the different types of varieties/genotypes, harvest time,

Table 3 - Total anthocyanin content (TAC), Antioxidant capacity (DPPH radical-scavenging assay and Ferric reducing antioxidant capacity – FRAP assay), and total phenolic content (TPC) of purple-fleshed sweet potato (PFSP), lyophilized purple-fleshed sweet potato powder (LP), and Greek yogurt fortified with lyophilized purple-fleshed sweet potato powder (LP).

	----------Results in dry base----------				
	PFSP	LP	Control (Yogurt)	A_2	A_4
TAC (mg cyanidin 3-glucoside 100 g^{-1})	$54.59^{a} \pm 2.64$	$51.10^{a} \pm 1.87$	n/a*	$1.16^{c} \pm 0.08$	$2.10^{b} \pm 0.27$
DPPH (µmol TE g^{-1}***)	$16.50^{b} \pm 0.55$	$20.64^{a} \pm 1.61$	$1.00^{c} \pm 0.06$	$0.95^{c} \pm 0.01$	$0.93^{c} \pm 0.06$
FRAP (µmol TE g^{-1}***)	$50.40^{b} \pm 6.90$	$112.93^{a} \pm 4.38$	$0.57^{e} \pm 0.08$	$2.86^{d} \pm 0.22$	$7.24^{c} \pm 0.57$
TPC (mg GAE g^{-1}**)	$88.13^{b} \pm 1.69$	$103.66^{a} \pm 3.35$	$0.42^{d} \pm 0.16$	$0.75^{d} \pm 0.18$	$1.22^{c} \pm 0.20$

[a–e] Different letters in the same line indicate significant differences ($P < 0.05$); *n/a: not applicable; **GAE: gallic acid equivalent; ***TE: trolox equivalent.

storage period, submission to boiling processes, and drying/dehydration conditions.

The addition of LP to yogurts did not promote an increase in the sequestration capacity of the DPPH radical. For TPC, increased bioactivity was only observed for A_4. The fortification with LP at 2 and 4% resulted in a significant increase in the bioactive capacity of Greek yogurt regarding the iron reduction capacity (FRAP). Studies concerning the fortification of yogurts using purple fleshed sweet potatoes are still incipient. However, there are several studies that report the supplementation of yogurts with different sources of anthocyanins. DU et al. (2021) quantified the TPC of yogurts supplemented with mulberry bagasse at 3 levels (1, 2, and 3%). The authors found TPC contents between 0.70 and 3.92 mg GAE g^{-1}. Both A_2 and A_4 are within the range reported by these authors. They also evaluated the TAC concentration and reported values ranging from 2.33 to 7.91 mg cyanidin 3-glucoside 100 g^{-1}, which were higher than the ones of the present study (1.16 and 2.10 mg cyanidin 3-glucoside 100 g^{-1}). ANUYAHONG et al. (2020) obtained lower results for yogurt supplemented with anthocyanin-rich rice: approximate values between 0.06 and 0.12 mg GAE g^{-1} for TPC and between 0.04 and 0.11 µmol TE g^{-1} for FRAP.

As expected, the addition of LP significantly increased ($P < 0.05$) the bioactive contents of yogurts through the occurrence of anthocyanins, which was more evident when LP was added at 4%. Although, the contributions in the antioxidant capacities of yogurts have occurred in a discrete way, the enrichment of this product using a natural matrix represent a suitable strategy to improve its nutritional quality (JASTER et al., 2018). Moreover, it is noteworthy that sweet potato anthocyanins have greater stability compared to those present in other vegetables, which favors their application (TSUKUI et al., 1999).

Ph, titratable acidity, and color

Ph and acidity are important parameters of quality and safety for yogurts as they confer characteristics related to identity and quality standards, as well as allow the natural maintenance of the microbiological parameters at safe levels (AHMAD et al., 2022). Over the 30 days of storage, none of the samples showed a significant difference in pH ($P < 0.05$), with values ranging from 4.33 to 4.46 (Figure 2).

Regarding the lactic acid content, samples A_2 and A_4 showed no significant differences ($P < 0.05$) throughout storage, while the control sample presented an increase in lactic acid level in 30 days (Figure 2). Differences among samples were only observed at 0 days of storage for control and A_2 samples.

Although, yogurts may present different levels of lactic acid in their composition, legal aspects should be followed. According to the Normative Instruction No. 46 (BRAZIL, 2007), the lactic acid content of yogurts should be between 0.6 and 1.5%, corroborating the results found in this study, where the samples presented values between 1.33 and 1.53% of lactic acid. These findings suggested that there was no accumulation of metabolic by-products from the activity of the starting microorganisms since there was no evident post-acidification. This condition is favorable since post-acidification is considered an undesirable event that causes a reduction in the shelf life and changes in the product's sensory characteristics (ANUYAHONG et al., 2020; GHASEMPOUR et al., 2020).

Color has a direct impact on product choice and food preferences, being an attribute related to product acceptance that induces hedonic expectations (AHMAD et al., 2022). The prepared yogurts and LP can be observed in figure 1.

The L^*, a^*, b^*, and ΔE values of yogurts are shown in table 4.

Compared to the control, the addition of LP at different levels significantly reduced L^* and b^* parameters, indicating that the samples became darker (Table 4). Moreover, a^* values increased, evidencing that the samples were closer to red, which can be observed in figure 1, since after the addition of LP the samples presented pink coloration. The results found in this study were similar to those reported in studies carried out with yogurts fortified with pigments of plant matrices, such as mulberry bagasse (DU et al., 2021), grape bagasse (DEMIRKOL & TARAKCI, 2018), and elderberry (CAIS-SOKOLIŃSKA & WALKOWIAK-TOMCZAK, 2021). The low variation of ΔE during storage is due to the higher resistance of PFSP anthocyanins.

Regarding the total color difference (ΔE) during storage, a minor variation was determined in sample A_4 compared to 0 days of storage. It indicated greater stability in the evaluated parameters (L^*, a^*, and b^*). Even with significant variations ($P < 0.05$), the color was relatively constant in samples since the maximum value of ΔE was 5.92 (Table 4). Such stability favors a possible application in dairy products as color is the first quality attribute evaluated by consumers and the low effect of storage time on color allows the offer of a uniform product (GHASEMPOUR et al., 2020). According to TSUKUI et al. (1999), due to the high degree of acylation, anthocyanins present in this

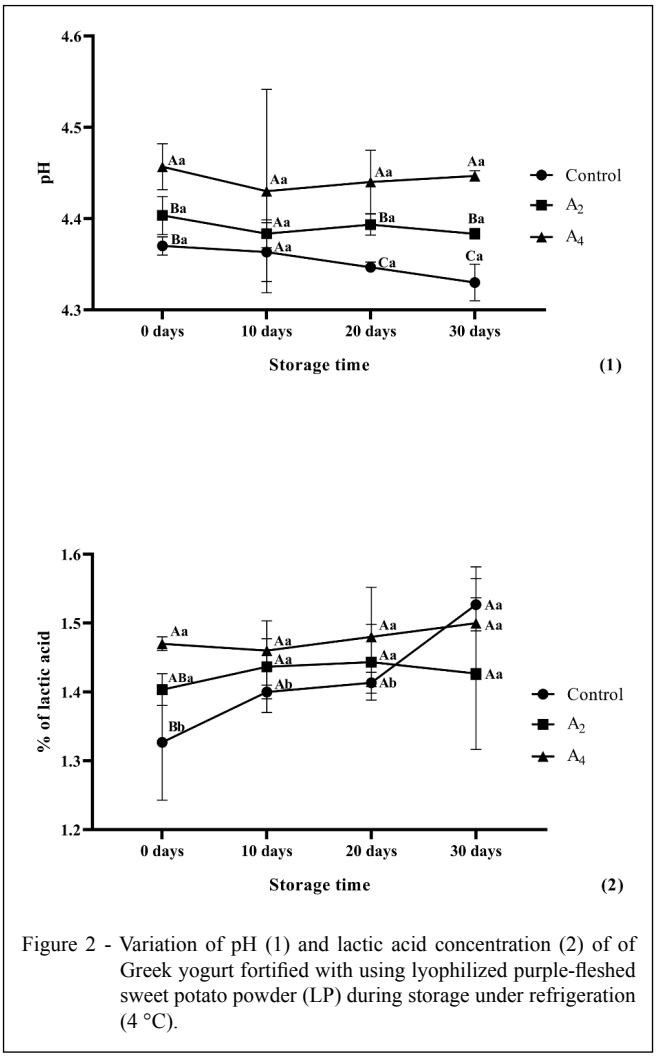

Figure 2 - Variation of pH (1) and lactic acid concentration (2) of of Greek yogurt fortified with using lyophilized purple-fleshed sweet potato powder (LP) during storage under refrigeration (4 °C).

tuber become more resistant to oxidation, heating, and irradiation of UV light when compared to other pigments and anthocyanins of other vegetables, such as apple, cabbage, and strawberry.

Syneresis

Syneresis is an indicator of yogurt quality and represents the balance between the forces of attraction and repulsion within the casein network formed in yogurt production and the rearrangement capacity of the network formed with the addition of components (ANUYAHONG et al., 2020). When compared to each other, the samples showed significantly different ($P < 0.05$) results of syneresis for all storage times. During the 30 days of storage, the syneresis index of the 3 samples increased (Figure 3).

Control samples presented 4.52% of syneresis at 0 days and 5.62% at 30 days, while samples A_2 and A_4 showed the following results, respectively: 1.93% at 0 days and 3.21% at 30 days; 0.15% at 0 days and 0.45% at 30 days. The release of water is undesirable and may lead to consumers rejection (GHASEMPOUR et al., 2020). It is possible to observe that for A_4 the syneresis is almost nil. For control and A_2, the maximum values recorded were 5.62% and 3.21%, respectively. The low rates are due to the type of product. Greek yogurt is a concentrated and drained dairy product, where most of the water comes out in the whey (JRAD et al., 2019).

The addition of LP promoted the increase of solids content, considerably reducing yogurt syneresis and corroborating the results described by other authors. DU et al. (2021) evaluated the effects of mulberry pomace addition in yogurts and revealed that the increase in water retention capacity was proportional to mulberry pomace dosages.

Table 4 - Color (parameters L^*, a^*, b^*, and ΔE) of Greek yogurt fortified with lyophilized purple-fleshed sweet potato powder (LP) during storage under refrigeration (4 °C).

Parameter	--------Sample--------	--------0 days--------	--------10 days--------	--------20 days--------	--------30 days--------
L^*	Control	$90.61^{Aa} \pm 0.82$	$84.72^{Bb} \pm 1.28$	$79.91^{Cb} \pm 0.91$	$76.61^{Ca} \pm 1.67$
	A_2	$86.29^{ABb} \pm 1.72$	$87.91^{Aa} \pm 0.30$	$83.86^{Ba} \pm 0.17$	$79.39^{Ca} \pm 1.62$
	A_4	$81.55^{Ac} \pm 0.04$	$81.86^{Ac} \pm 0.37$	$81.26^{Aab} \pm 1.67$	$78.39^{Aa} \pm 2.01$
a^*	Control	$0.72^{Ac} \pm 0.02$	$0.59^{Ac} \pm 0.06$	$0.60^{Ac} \pm 0.06$	$0.67^{Ac} \pm 0.03$
	A_2	$5.67^{Ab} \pm 0.13$	$4.83^{Bb} \pm 0.05$	$4.88^{Bb} \pm 0.01$	$4.67^{Bb} \pm 0.09$
	A_4	$8.53^{Aa} \pm 0.01$	$7.73^{Ba} \pm 0.08$	$7.53^{Ba} \pm 0.06$	$7.65^{Ba} \pm 0.27$
b^*	Control	$12.12^{Aa} \pm 0.01$	$11.57^{Aa} \pm 0.31$	$11.72^{Aa} \pm 0.19$	$11.79^{Aa} \pm 0.18$
	A_2	$3.55^{Ab} \pm 0.35$	$3.47^{Ab} \pm 0.38$	$3.21^{Ab} \pm 0.25$	$2.91^{Ab} \pm 0.09$
	A_4	$2.51^{Ac} \pm 0.01$	$2.45^{Ac} \pm 0.08$	$2.38^{Ac} \pm 0.07$	$2.50^{Ac} \pm 0.13$
ΔE	Control	n/a*	$5.92^{Aa} \pm 0.50$	$4.81^{ABa} \pm 0.40$	$3.30^{Ba} \pm 0.79$
	A_2		$2.38^{Ab} \pm 0.93$	$4.06^{Aa} \pm 0.30$	$4.50^{Aa} \pm 1.79$
	A_4		$0.94^{Cb} \pm 0.02$	$2.15^{Bb} \pm 0.18$	$2.90^{Aa} \pm 0.33$

$^{A–C}$ Different letters in the same line indicate significant differences; $^{a–c}$ Different letters in the same column for the same parameter indicate significant differences ($P < 0.05$); *n/a: not applicable.

ANUYAHONG et al. (2020) observed the reduction of syneresis in yogurts incorporated with high-anthocyanin content rice. According to DÖNMEZ et al. (2017), reductions of syneresis increase the water capacity within the existing gel network.

Improvements in syneresis with the addition of LP to Greek yogurt may be due to two points: 1) polyphenols can form soluble complexes with casein. From the hydrophobic interaction of the casein network, associated with the parallel emergence of hydrogen bonds, such complexes are stabilized, which limits the release of the whey (ANUYAHONG et al., 2020); 2) The water retention capacity of starch can promote protein-protein interactions, which makes the structure of the protein network more structured and reticulated, reducing water expulsion (JIA et al., 2022).

Apparent viscosity and texture analysis

Figure 4 shows the results of apparent viscosity. The samples showed pseudoplastic behavior. With the increase in the shear rate, the

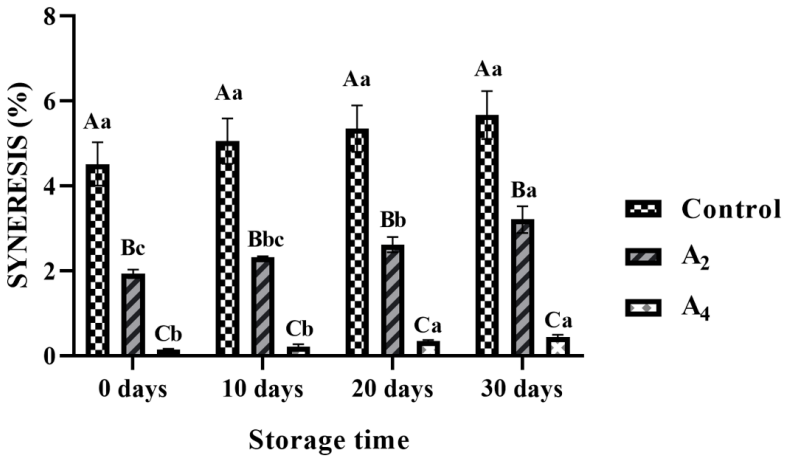

Figure 3 - Syneresis of Greek yogurt fortified with using lyophilized purple-fleshed sweet potato powder (LP)during storage under refrigeration (4 °C).

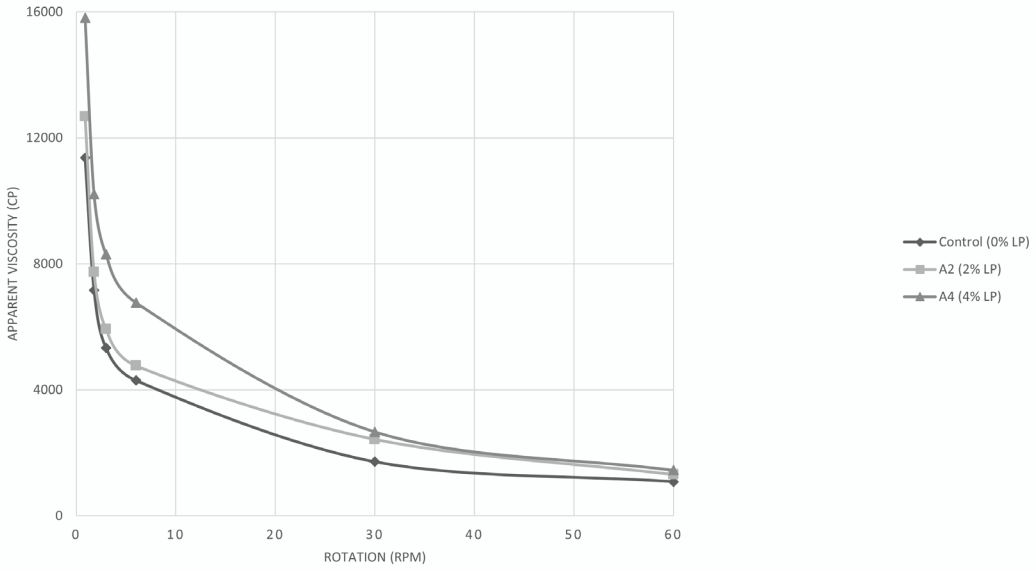

Figure 4 - Apparent viscosity of Greek yogurt fortified with using lyophilized purple-fleshed sweet potato powder (LP).

chains that were previously arranged randomly start to align in the direction of the flow, resulting in a lower interaction between the existing polymer chains (PÉREZ et al., 2021). An increase in apparent viscosity was also observed with the addition of LP, being more evident at the level of 4%.

Regarding the texture profile, no significant differences were observed ($P < 0.05$) for adhesiveness and springiness between samples. For hardness and gumminess, A_4 differed from control and A_2, while for chewiness, A_4 differed only from control (Figure 5). The addition of 4% LP promoted an improvement in texture, allowing the production of firmer yogurts with greater chewability and gummy.

According to ANUYAHONG et al. (2020), these are important quality parameters of yogurts. Improvements in yogurt texture parameters have been reported by several authors. DU et al. (2021) also observed an increase in apparent viscosity when enriched yogurt with blackberry bagasse. ZYGMANTAITĖ et al. (2021) and CAIS-SOKOLIŃSKA & WALKOWIAK-TOMCZAK (2021) obtained more viscous yogurts from cranberry bagasse and elderberry juice enrichment, respectively. However, it is believed that the textural alterations of yogurts are due to interactions promoted with starch, since LP presents in its composition around 53% of starch, being 75% of this percentage resistant starch (Table 2). The findings of this study corroborated the results reported by HE et al. (2019), who showed that the addition of two different types of resistant starches at 1.5% promoted an increase in the apparent viscosity of yogurts. PÉREZ et al. (2021) compared the impacts of adding starch from two varieties of yam in yogurt with the supplementation with pectin (food additive with thickening capacity) and observed that the yogurts added with starches had higher viscosity. In addition, JIA et al. (2022) reported that the addition of resistant starches from corn promoted the production of firmer yogurts as the starch swelling property plays an important role in yogurt texture.

These are desirable technological aspects since Greek yogurt is a product of relatively high firmness and consistency and its production without the use of chemical additives allows meeting the clean label market demand (JRAD et al., 2019; ASIOLI et al., 2017).

CONCLUSION

Purple-fleshed sweet potato powder is a natural versatile food additive that plays a role in color promotion, texture improvement, and maintenance of parameters of identity and quality of yogurts. The addition of LP resulted in pink firmer yogurts with greater chewability, low color variation throughout storage, and with attenuated post-acidification. Additionally, the bioactive capacity of the product

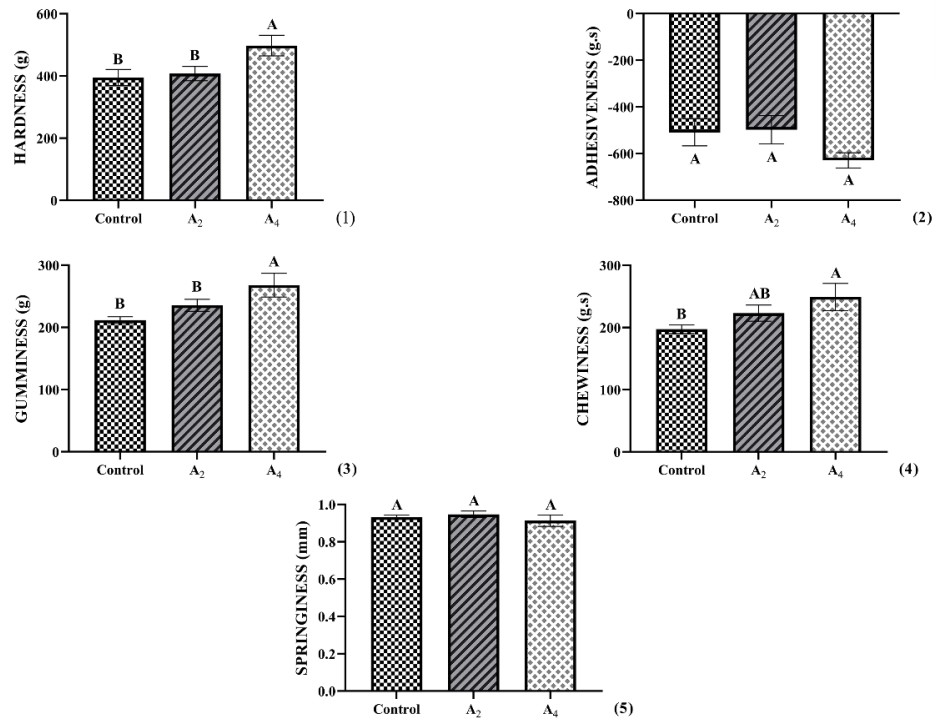

Figure 5 - Texture Profile [Hardness (1), Adhesiveness (2), Gumminess (3), Chewiness (4), and Springiness (5)] of Greek yogurt fortified with using lyophilized purple-fleshed sweet potato powder (LP).

increased by adding a matrix rich in anthocyanins and the syneresis considerably reduced – an important parameter to the consumers' acceptability.

The nutritional quality of purple-fleshed sweet potato and its freeze-dried powder stimulates future studies regarding applications in different matrices. Moreover, obtaining an additive from a natural and renewable source with nutritionally attractive characteristics meets the consumers' demand for products that fit within the clean label movement.

The results achieved in this research were promising and yogurts can be considered excellent products for the application of freeze-dried powder of purple-fleshed sweet potato. However, even with these encouraging results and perspectives, further studies are needed to evaluate the sensory acceptance of this kind of product by consumers.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. Sponsors had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally to the conception and writing of this manuscript. All authors critically revised the manuscript and approved the final version.

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