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Water-soluble oat extract enriched with mango peel flour: preparation, characterization and application in Greek yogurt

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Abstract: This study aimed to produce water-soluble oat extract enriched with mango peel flour (MPF) as a source of active compounds and to use this ingredient as a partial substitute for whole milk in Greek yogurt (GY) for its nutritional enrichment. Enriched water-soluble oat extracts (EWSOE) were produced with different concentrations of MPF (0%, 1%, 1.5% and 2%) and characterized in relation to pH, titratable acidity, soluble proteins and total phenolics. Three GY formulations were prepared by partially replacing whole milk with EWSOE and the best formulation (in relation to sensory analyzes and phenolics compounds) was selected for storage study, chemical characterization, and sensory acceptance testing. MPF addition increased soluble proteins and total phenolics in EWSOE. GY formulations prepared with EWSOE had similar sensory scores. During storage, GY prepared with EWSOE containing 2% MPF exhibited changes in pH and titratable acidity and a reduction in total phenolics. Color parameters, cholesterol, and fatty acid composition did not change over 21 days of storage. The major fatty acids in GY were oleic and palmitic acids. The selected product had low lactose content (1.2%), achieved satisfactory sensory acceptance in relation to the evaluated attributes, and had lipid (~6.19%) and protein (~3.96%) contents within regulatory requirements. Additionally, EWSOE is a valuable ingredient in GY preparation, offering beneficial nutritional and functional properties.

Key words: by-product, enriched food, functional, nutritional value.

INTRODUCTION

Novel plant-based foods and beverages have been continuously released on the market to meet the growing demand for animal product alternatives (Montemurro et al. 2021). An example of such products are water-soluble plant extracts based on cereals, pseudocereals, seeds, nuts, fruits, and vegetables (Rincon et al. 2020). These products are chosen by an increasing number of consumers as a substitute for whole milk, either for health or lifestyle reasons. Plant extracts can be easily fermented and used as a basis for the preparation of highly palatable products, increasing protein digestibility and micronutrient bioavailability (Marsh et al. 2014).

With a high nutritional value, oat is an interesting cereal for the preparation of water-soluble extracts. Compared to other alternative sources for water-soluble extract production, such as soy and almond, oat-based substitutes have relatively high fiber content, approximately 2% (Cui et al. 2023). Oat contains considerable amounts of proteins, total fibers, and beta glucan, a type of soluble fiber that forms a thick gel as it passes through the intestine (Paul et al. 2019). Beta glucan exerts a prebiotic effect on the gastrointestinal tract, supporting the development of beneficial microorganisms; the compound also binds to cholesterol, reducing its absorption (Angelov et al. 2018).

Water-soluble oat extracts represent a valuable addition to the diet of individuals with dietary restrictions, as it is lactose- and gluten-free (Deora & Deswal 2018). According to Cui et al. (2023) the water-soluble oat extract has a smooth texture and flavor, increasing its acceptance by consumers and making it a popular drink, in addition to being a source of essential nutrients for the human body. Other important components found in oat extracts include polyphenols and avenanthramides, which have high antioxidant activity and contribute to the prevention of coronary heart disease (Dhanalakshmi 2021). Oat is also a good source of micronutrients, such as vitamins (A, C, D, B6, B9 and B12), copper, iron, selenium, and zinc, which collectively contribute to the development and maintenance of a healthy immune system (Chen et al. 2021).

Campos et al. (2018) studied the partial replacement of whole milk with water-soluble oat extract in the preparation of Greek yogurt. This change resulted in an improvement in sensory properties (taste, consistency, and texture) and a reduction in lactose content. Atwaa et al. (2020) partially replaced camel milk with oat milk in yogurt formulations and observed improvements in physicochemical, rheological, antioxidant, microbiological, and sensory properties. Godoy-García et al. (2020) produced Greek-style yogurt with added glycomacropeptide and observed that glycomacropeptide at a concentration of 0.75%, besides contributing to the increase of S. *thermophilus*, reduced syneresis, extended shelf life, and also decreased the lipid content present in the yogurt. Greek yogurt is a product with higher total solids content and lower lactose content compared to traditional yogurts, and it offers various benefits primarily due to its higher protein content and the benefits associated with lactic acid bacteria (Víquez-Barrantes et al. 2023). Additionally, it is considered a healthier option among consumers (Jørgensen et al. 2019) and according to data from the Business Research Insights Greek Yogurt Market Report (2023), the global Greek yogurt market size was US$ 5,751.96 million in 2021 and the market is expected to reach US$ 8,529.31 million in 2027.

The nutritional value of water-soluble oat extracts can be further enhanced by adding ingredients rich in bioactive compounds, such as fruit byproducts, which contain high levels of polyphenols (Majerska et al. 2019) and have high antioxidant activity. Mango peel, for instance, is a source of phenolic compounds, vitamins C and E, dietary fibers, and minerals such as magnesium and potassium (Durua et al. 2019, Diomande et al. 2021). Additionally, it contains considerable amounts of protocatechuic acid, mangiferin, and β-carotene, which have antidiabetic, antiviral, anticancer, and anti-inflammatory properties (Gupta et al. 2022). Lauricella et al. (2019) observed that mango peel extract exerts remarkable cytotoxic effects on human colon cancer cells, affecting cell viability and inhibiting colony formation. Marçal & Pintado (2021) reported that mango peel extracts are a good source of co-pigments (e.g., penta- and hexa-*O*-galloyl-glucose) and lipid peroxidation inhibitors, acting in the prevention of inflammatory diseases.

In view of the foregoing, this study aimed to prepare a water-soluble oat extract enriched with mango peel flour and utilize it as a partial substitute for whole milk in the preparation of Greek yogurt. Four water-soluble extract formulations were developed and characterized. Subsequently, three yogurt formulations were prepared and subjected to microbiological and sensory analyses. The best yogurt formulation was selected for improvement of the straining process. Finally, the improved product was evaluated for storage stability, physicochemical parameters, texture profile, and sensory acceptance.

MATERIALS AND METHODS

Materials

Pasteurized whole milk (Umuleite) and fine oat flakes (Yoki Alimentos S.A., lot E22BRMP04M, expiration date May 4, 2023) were purchased from a local market in Umuarama, PR, Brazil. The yogurt starter culture YI-GO 5 U (lyophilized culture of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*) was obtained from Biotech Brasil Fermentos e Coagulantes Ltda. Fruits of mango 'Tommy Atkins' were obtained through a partnership with the food waste reduction program of the Umuarama Food Bank.

Sodium hydroxide solution (Neon) and phenolphthalein (Neon) were used for acidity determination. Copper sulfate pentahydrate (Synth), sodium citrate (Dinâmica), sodium carbonate (Anidrol), sodium hydroxide (Neon), Folin–Ciocalteu reagent (Sigma–Aldrich), and bovine albumin (A7906, Sigma-Aldrich) were used to determine soluble proteins. Sulfuric acid (Anidrol), hydrochloric acid (Anidrol), sodium hydroxide (Neon), and boric acid (Synth) were used for analysis of crude protein content. Folin–Ciocalteu reagent (Sigma–Aldrich), sodium carbonate (Êxodo Científica), and gallic acid (Sigma–Aldrich) were used for determination of total phenolic compounds.

Peptone water (HiMedia) and Man–Rogosa–Sharpe agar (HiMedia) were used for microbiological analysis. Chloroform (Dinâmica) and methanol (PanReac) were used for extraction of the lipid fraction. Acetone (Synth), sulfuric acid (Anidrol), amyl alcohol (Êxodo Científica), and sodium hydroxide (Neon) were used for determination of total fibers. The following reagents were used to determine lactose content: potassium ferrocyanide trihydrate (Neon), sodium hydroxide (Neon), zinc sulfate heptahydrate (Êxodo Científica), and methylene blue (Êxodo Científica).

Sodium hydroxide (≥97.0%, Anidrol), sulfuric acid (>95.0%, Anidrol), heptane (99.0% purity, Synth), *N*,*O*-bis(trimethylsilyl)trifluoroacetamide (BSTFA, ≥99.0%, Sigma–Aldrich), and 5α-cholestane (98%, Sigma–Aldrich) were used for determination of fatty acid composition and cholesterol content.

Preparation of raw materials

Fine oat flakes containing 9.09% ± 0.11% moisture were used without any previous treatment. For the production of mango peel flour, the fruits were washed under running water and sanitized with sodium hypochlorite solution (200 ppm) for 15 min. Subsequently, fruits were peeled and separated from the pulp by using a knife. The peels were arranged in trays and oven-dried at 70 °C for 12 h, reaching 5.88% ± 0.53% moisture. Dried peels were processed into flour by using a blender (Britannia), sieved through 100 mesh sieves (Tyler), and stored in a previously sterilized glass bottle.

Preparation and characterization of plant extract

For preparation of enriched water-soluble oat extracts (EWSOE), 100 g of oat flakes was added to 500 mL of water, and the mixture was allowed to stand for 2 h. Then, the mixture was ground in a blender (Britania), and 1000 mL of water at 100 °C was added. The resulting material was filtered, and mango peel flour was added according to each formulation (Table I). Flour concentrations were defined based on preliminary tests, which showed the ranges that did not produce significant alterations in the

Table I. Formulations of water-soluble extracts from oats with the addition of mango peel flour.

Ingredient	Formulation			
	F1	F2	F3	F4
Water-solubleextract (mL)	250	250	250	250
Mango peelflour (%)[1]	0	1	1.5	2

[1] **in relation to water-soluble extract.**

color of the final product. The flour was fully incorporated into the extract by using a spatula. Subsequently, samples were left to stand for 30 min, blended for 1 min, and filtered to obtain EWSOE, which was stored under refrigeration at 5 ± 1 °C (Consul/CRB36ABANA) until use.

EWSOE formulations were characterized for pH, titratable acidity, soluble proteins, and total phenolics. The pH was determined by using a pre-calibrated digital pH meter (Gehaka/PG 2000). Titratable acidity was determined by the method recommended by the Brazilian Ministry of Agriculture, Livestock, and Food Supply (Brasil 1986). Soluble protein and total phenolic contents were determined according to Lowry et al. (1951) and Singleton et al. (1999), respectively.

Preparation of Greek yogurt

Greek yogurt was prepared according to the procedures described by Campos et al. (2018), with 50% replacement of whole milk with EWSOE, resulting in formulations F2, F3 and F4. First, pasteurized whole milk and EWSOE were separately heated to 42 °C. The liquids were combined and the starter culture was added at a ratio of 17.5 mL to 1 L. After gentle homogenization, samples were incubated at 42 °C in an air-circulation oven (Marconi MA035), until pH 3.92 was reached (6 h), as recommended by the Food and Drug Administration (FDA 2022).

Straining was performed under refrigeration (5 ± 1 °C) (Consul/CRB36ABANA) for 12 h by using a sanitized set of sieves equipped with tissue filters. After straining, the product was placed in sanitized plastic containers and stored aseptically in a refrigerator (Consul/CRB36ABANA) at 4 °C.

After sensory evaluation of yogurt formulations, F4 was selected for further analysis. Given the low scores attributed to consistency, the straining time was increased to 72 h.

Characterization of Greek yogurt

Microbiological and sensory analyses of yogurt formulations

Total coliforms (35 °C) and thermotolerant coliforms (45 °C) were determined according to the legislation on fermented milk beverages (Brasil 2003). Sensory analysis was performed according to the method of the Adolfo Lutz Institute (IAL 2008) and was approved by the Ethics Committee at the Universidade Estadual de Maringá (CEP/CONEP-CAAE protocol No. 56038122.7.0000.0104). The panel comprised 102 untrained tasters, including students and staff of the Universidade Estadual de Maringá, of both sexes, aged 18 to 65 years.

The tasters received a portion (6 g) of each formulation (F2, F3 and F4) in plastic cups. Cups were randomly coded with three-digit numbers. The yogurt was served at about 4 °C, accompanied by a glass of water. Samples were presented to tasters in a monadic sequential manner. Overall liking was rated on a 9-point scale ranging from 1 (disliked extremely) to 9 (liked extremely). A bi-directional scale was used for the assessment of appearance, aroma, flavor, and consistency. These sensory parameters were rated on a structured 5-point scale anchored by 1 (extremely higher than the ideal) to 5 (extremely lower than the ideal), with the midpoint representing the ideal condition. Purchase intent was evaluated on a 5-point scale ranging from 1 (certainly would not buy) to 5 (certainly would buy).

Storage study

The pH, titratable acidity, and total phenolic content of yogurt formulations were determined as described above for the water-soluble extract. Color parameters were evaluated using a colorimeter (Minolta®). Fatty acid composition and cholesterol content were determined by gas chromatography coupled to mass spectrometry (Shimadzu, CGMS-QP2010 SE). Compounds were identified by comparison with the NIST mass spectral library (version 2014).

Cholesterol content was determined after derivatization of the lipid fraction with BSTFA/TMCS at 60 °C for 30 min, with subsequent addition of the standard 5α-cholestane. Samples were analyzed using the analysis conditions described by Cuco et al. (2019). Fatty acid analysis was performed as reported by Trentini et al. (2018). The hypocholesterolemic/hypercholesterolemic ratio (H/H) was calculated as reported by (Santos-Silva et al. 2002).

Stability assessment

Based on previous results, the formulation that yielded the best results in terms of sensory analysis and phenolic compounds was chosen for the experiments.

Microbiological parameters were determined as described above for yogurt formulations. Moisture, ash, total proteins, and total fiber were determined according to Adolf Lutz Institute methods (IAL 2008). The lipid fraction was extracted by the Bligh and Dyer method (Bligh & Dyer 1959), and carbohydrate content was obtained by difference. Lactose content was determined according to the guidelines of the Brazilian Ministry of Agriculture, Livestock, and Food Supply (Brasil 2007), by the Lane–Eynon method (Redutec, Marconi/MA-087). Whole milk was used as positive control.

Syneresis was analyzed according to Guirguis et al. (1984), based on the straining of yogurt under refrigeration (5 ± 1 °C) for 2 h. Texture parameters (firmness, cohesiveness, consistency, and viscosity) were determined using a texture analyzer (TA.XTExpress, Stable Microsystems®, London, England) equipped with a 36 mm diameter stainless steel probe (P36R) and Texture Exponent Lite® software. The test was conducted under the following conditions: compression depth of 10 mm, test speed of 1 mm/s, pre-test speed of 1 mm/s, post-test speed of 10 mm/s, and force of 1 g.

Sensory evaluation of aroma, color, flavor, texture, and overall appearance was performed using a structured 9-point hedonic scale ranging from 1 (disliked extremely) to 9 (liked extremely). The questionnaire also included the following questions: Do you usually eat Greek yogurt? Would you buy this product? The panel comprised 100 untrained tasters, including students and staff of the State University of Maringá, of both sexes, aged 18 to 65 years. Tasters received a portion (6 g) of the sample at 4 °C in a plastic cup.

Data analysis

The analyses were performed in triplicate (n = 3), each yogurt formulation being produced in 3 different times, totaling 9 samples for each formulation. Analysis of variance (ANOVA) followed by Tukey's test ($p < 0.05$) was conducted to determine differences between means. Analyses were performed using SAS version 9.3.

The results are expressed as mean ± standard deviation.

RESULTS AND DISCUSSION

EWSOE characterization

Table II shows the physicochemical characteristics of EWSOE. Addition of mango peel flour increased the pH of the extract. Nevertheless, pH values remained lower than 6. Acidity also increased with the addition of mango peel flour, possibly due to the presence of organic acids in the material (Láscaris et al. 2020). Increased acidity is favorable for storage, as organic acids hinder the development of spoilage microorganisms.

Addition of mango peel flour resulted in an increase in protein content, of about 30%, compared with the control. However, protein contents were still low. In a similar experiment, Almeida et al. (2020) found that water-soluble oat extract had a protein content of 2.04%, not being considered a protein drink. The main nutrients of cereals are carbohydrates (Philippi 2014), which explains why cereal-based drinks have low protein content.

Total phenolic content increased proportionally to the addition of mango peel flour. As reported by Alanón et al. (2021), mango peel is a source of phenolic compounds, containing 78.45 mg gallic acid equivalents per gram. Incorporation of microcapsules of mango peel extract in a milk drink increased polyphenol content, polyphenol bioavailability, and antioxidant activity (2- to 3-fold), as observed in a digestion simulation assay (El-Messery et al. 2021).

The total phenolic content of the control was expressive, albeit lower than that of extracts containing mango peel flour. Whole oats are an important source of phenolic compounds, associated with their various biological activities, such as antidiabetic, anticancer, and anti-inflammatory (Soycan et al. 2019). Intestinal modulation, composition and function of the intestinal microbiome, can be developed by phenolic compounds. Several studies carried out in vitro and in vivo, in general, attested that phenolic compounds reduce the incidence of environmental bacteria, while increasing the amount of beneficial bacteria, which act in the regulation of intestinal dysbiosis, and were indicated as capable of modulating food allergies and possibly reducing their symptoms (Simões et al. 2024). Phenolic compounds act as potent antioxidants, helping to prevent and treat neurodegenerative diseases, such as Alzheimer's and Parkinson's (Tayan et al. 2024).

Table II. Values of pH, acidity, soluble protein content and total phenolic compound (TPC) content of water-soluble extracts from oats with the addition of different concentrations of mango peel flour.

Formulation[1]	pH	Titratable acidity (% Laticacid)	Soluble protein (g per 100 g extract)	TPC content (mg GAE per 100 g extract)
F1	4.75±0.06[d]	0.19±0.05[c]	0.44±0.02[b]	7.03 ± 0.42[d]
F2	5.62±0.06[b]	2.52±0.27[b]	0.45±0.02[b]	35.39 ± 0.22[c]
F3	5.46±0.02[c]	2.76±0.22[ab]	0.64±0.11[ab]	47.42 ± 0.54[b]
F4	5.84±0.06[a]	2.93±0.26[a]	0.65±0.07[a]	58.44 ± 0.65[a]

[1]as Table I. GAE: gallic acid equivalent. Means followed by the same lowercase letter (in each column) do not differ statistically (p> 0.05).

Characterization of Greek yogurt

Formulation selection

The total and thermotolerant coliform counts of Greek yogurt formulations were <10 and <3 most probable number (MPN) mL^{-1}, respectively. According to the Technical Regulation of Identity and Quality of Milk Drinks (Brasil 2007), the maximum threshold for fermented milk beverages is 100 MPN mL^{-1} total coliforms and 10 MPN mL^{-1} thermotolerant coliforms. Therefore, all formulations met the microbiological criteria established by legislation, being considered suitable for consumption.

Table III describes the sensory scores, purchase intent, and overall liking of Greek yogurt formulations. The formulations had similar sensory attributes, and none of the panelists rated the samples as "extremely lower than the ideal." Thus, addition of mango peel flour did not seem to affect acceptance.

Although the overall linking scores of Greek yogurt formulations were near the midpoint (neither like nor dislike), the scores for appearance, aroma, and consistency were near 3 (ideal). The findings indicate overall consumer satisfaction with the product (Popper 2014). The mean scores for taste (ideal) and purchase intent (might or might not buy) were close to 3.

In light of the results, F4, which had the highest content of mango peel flour, was selected for further analysis. However, the straining time of the formulation was increased to improve consistency.

Stability during storage

Table IV shows the pH, titratable acidity, total phenolic content, color parameters, fatty acid composition, and cholesterol content of the Greek yogurt formulation during refrigerated storage. The pH was within the limits recommended by the FDA for yogurt, namely pH 4.6 or lower. The decrease in pH over time was accompanied by an increase in titratable acidity during the 21-day storage period. This downward trend in pH during storage was also observed by Chen et al. (2018) for fortified chickpea yogurt and by Manzoor et al. (2019) for yogurt enriched with papaya peel powder.

The titratable acidity was within regulatory limits (0.6% to 1.5% lactic acid) (Brasil 2007). The decline in pH and increase in titratable acidity, particularly in yogurts fortified with fruit byproducts, can be attributed to the production of lactic acid during storage (Casarotti et al. 2018). During this period, there is an increase

Table III. Sensory evaluation scores for Greek yogurt with partial replacement of whole milk by water-soluble extract from oats enriched.

Attribute	Formulation[1]		
	F2	F3	F4
Appearance	3.1±1.0[a]	3.2±1.1[a]	3.1±1.1[a]
Aroma	3.2±1.0[a]	3.3±1.1[a]	3.3±1.1[a]
Consistency	2.9±1.2[a]	3.0±1.3[a]	3.0±1.2[a]
Flavor	2.6±1.1[a]	2.6±1.2[a]	2.7±1.1[a]
Purchase intension	2.8±1.2[a]	2.8±1.3[a]	2.9±1.2[a]
Global acceptance	5.5±1.8[a]	5.5±2.3[a]	5.6±1.9[a]

[1]as Table I. Means followed by the same lowercase letter (in each line) do not differ statistically (p> 0.05).

in the activity of lactic bacteria, which consume lactose from yogurt and produce lactic acid, making yogurt more acidic. Nevertheless, acidity remained stable up to 14 days of storage, with a significant difference at 21 days.

Straining alters the composition of Greek yogurt, with an increase in total solids content, as evidenced by the increase in total phenolic compounds compared with EWSOE (Table II). During fermentation, microorganisms produce enzymes that release phenolic compounds from the substrate matrix. Therefore, the release of phenolic compounds from mango peel can have a positive effect on the antioxidant properties of Greek yogurt (Vicenssuto & Castro 2020).

Total phenolic content decreased over storage from day 1 to 7, not varying from day 10 onward. Such a decrease in total phenolic content can be attributed to the slow decomposition of phenolic compounds and the generation of aromatic acids, such as phenylpropionic, acetic, and benzoic acids, during refrigerated storage (Zahid et al. 2022). Studies have shown that probiotic bacteria present in yogurt fortified

Table IV. **Evaluation of the characteristics of Greek yogurt (formulation F4) during storage at 4 °C.**

Property		Storage time (day)			
		1	7	14	21
pH		3.90±0.01[a]	3.77±0.07[b]	3.85±0.01[ab]	3.75±0.07[c]
Titratable acidity (% Latic acid)		1.04±0.10[a]	1.11±0.03[a]	1.10±0.04[b]	1.38±0.03[a]
Total phenolic compounds (mg GAE 100 g^{-1})		176.76±1.21[a]	166.39±3.21[b]	160.49±1.34[c]	158.42±2.92[c]
Color parameters	L*	78.95±0.37[a]	78.24±0.67[a]	77.25±0.34[b]	75,84±0,52[c]
	a*	-0.65±0.02[a]	-0.77±0.19[a]	-0.74±0.03[a]	-0,53±0,03[b]
	b*	18.78±0.11[b]	19.19±0.13[a]	19.66±0.18[a]	19,51±0,07[a]
Cholesterol (mg 100 g^{-1})		243.53±4.39[a]	245.25±0.69[a]	242.59±5.17[a]	240.53±6.62[a]
Fatty acid (%)	Caprylic	0.63±0.01[a]	0.59±0.00[a]	0.61±0.03[a]	0.61±0.03[a]
	Caprico	1.75±0.03[a]	1.72±0.00[a]	1.75±0.01[a]	1.80±0.11[a]
	Lauric	2.58±0.05[a]	2.48±0.04[a]	2.51±0.01[a]	2.48±0.02[a]
	Mystic	10.19±0.13[a]	10.08±0.00[a]	10.12±0.16[a]	9.99±0.00[a]
	Tridecanoic	0.36±0.02[a]	0.36±0.03[a]	0.34±0.01[a]	0.38±0.01[a]
	Tetradecanoic	0.59±0.03[a]	0.61±0.01[a]	0.60±0.01[a]	0.64±0.03[a]
	Pentadecanoic	1.15±0.01[a]	1.11±0.04[a]	1.10±0.01[a]	1.24±0.13[a]
	Palmitic	32.00±0.10[a]	32.36±0.06[a]	32.25±0.07[a]	32.36±0.13[a]
	Palmitoleic	1.36±0.03[a]	1.32±0.02[a]	1.33±0.04[a]	1.30±0.00[a]
	Margaric	0.84±0.07[a]	0.80±0.05[a]	0.79±0.00[a]	0.83±0.04[a]
	Stearic	12.00±0.18[a]	12.16±0.01[a]	11.99±0.06[a]	11.85±0.07[a]
	Oleic	26.73±0.21[a]	26.86±0.12[a]	26.83±0.05[a]	26.89±0.03[a]
	Linoleic	5.90±0.06[a]	5.70±0.02[a]	5.77±0.03[a]	5.75±0.03[a]
	Linolenic	0.40±0.02[a]	0.40±0.00[a]	0.37±0.00[a]	0.37±0.00[a]
	Others	3.64±0.11[a]	3.44±0.01[a]	3.54±0.03[a]	3.49±0.01[a]

GAE: gallic acid equivalent. Means followed by the same lowercase letter (in each line) do not differ statistically (p> 0.05).

with fruit byproducts hydrolyze polyphenols (Kabir et al. 2021).

According to Pasquet et al. (2024), in foods with acidic pH, phenolic acids, catechins, and related compounds are more stable against oxidation. However, after a few days of storage, a reduction in the levels of phenolic compounds was observed, and possibly this reduction may have occurred due to the breakdown of polyphenols in the presence of lactic acid bacteria during storage. According to Dalling (1986), flavonols are broken down into catechin polymers, resulting in a reduction in the total phenolic compound content.

Abdel-Hamid et al. (2022) reported that during fermentation, molecular changes occur in milk, leading to the degradation of primary compounds into various secondary compounds with antioxidant properties. Possibly, the same effect occurred during the fermentation process of yogurt with water-soluble oat extracts, and these interactions between milk compounds (proline group) and the hydroxyl group of phenolic compounds may result in the precipitation of phenolic compounds, decreasing their final concentration.

*L** (lightness) differed from 14 days of storage onward. The parameter decreased, indicating greater opacity. The values of *a** (greenness/redness) were negative, demonstrating that yogurt had a slight tendency toward green. The parameter *b** represents the intensity of blueness/yellowness. This parameter increased at 7 days of storage, indicating a yellowish color. This finding is evidence of the influence of mango peel flour on the color of Greek yogurt.

The cholesterol content and fatty acid composition of the sample remained stable during storage. Palmitic and oleic acids were the predominant fatty acids in Greek yogurt. Linolenic (omega 6) and linoleic (omega 3) acids together accounted for 6.16% of the total fatty acid content. Such a composition can be attributed to the use of oats and mango peel flour. Similar data were reported by Paszczyk & Czarnowska-Kujawska (2022), who indicated that natural yogurts containing muesli and cereal grains had a significantly higher content of these essential fatty acids compared with the other tested yogurts.

H/H refers to the functional activity of fatty acids in lipoprotein metabolism for the transport of plasma cholesterol. The ratio is also related to cardiovascular disease risk (Paszczyk & Czarnowska-Kujawska 2022). In the current study, the H/H value was 0.74%, higher than that observed by Ahmad et al. (2021) for natural whole milk yogurt (0.54%). Higher H/H values are desirable, as they are indicative of a higher content of hypocholesterolemic fatty acids, which are beneficial to human health (Kasapidou et al. 2022).

Characterization of the final product

Table V presents the results of physicochemical, syneresis, texture, and sensory evaluation of the tested Greek yogurt formulation. The total and thermotolerant coliform contents were within regulatory limits (<10 and <3 MPN mL^{-1}, respectively). Moisture content is influenced by the production process, in particular, straining time. Straining is carried out to reduce the water content and concentrate solids, such as proteins, lipids, and ash (Escalona-Jiménez et al. 2022). The lipid and protein contents of the Greek yogurt formulation were within regulatory limits (≥3% and ≥2.9%, respectively) (Brasil 2007).

Addition of EWSOE influenced the fiber content of Greek yogurt, given the high fiber levels of the raw materials. The fortified Greek yogurt had a 1.53% fiber content, similar to yogurt fortified with 2% cranberry pomace (1.45% fiber) (Varnaité et al. 2022). Despite not being considered a source of fiber, Greek yogurt

Table V. **Physicochemical composition, texture and sensory evaluation of Greek yogurt (formulation F4).**

Property		Value
Moisture (%)		78.96±0.12
Lipids (%)		6.19±0.01
Proteins (%)		3.96±0.13
Fibers (%)		1.53±0.11
Ashes (%)		0.45±0.03
Carbohydrates (%)		8.91±0.01
Lactose content (%)		1.22±0.01
Syneresis(%)		6.77±0.21
Texture	Firmness (g)	24.01±0.38
	Consistency (g seg^{-1})	131.09±1.94
	Cohesiveness (g)	- 13.27±0.93
	Viscosity index (g seg^{-1})	- 6.67±0.30
Sensory attributes (hedonicscale)	Aroma	7.83±1.2
	Color	6.63±1.7
	Flavor	6.86±2.0
	Texture	7.43±1.5
	Overall appearance	7.17±1.5

prepared with EWSOE contains some amounts of fiber, which has several health-related benefits, compared with conventional Greek yogurt (0% total fiber).

The ash content of Greek yogurt was 0.45%, lower than that found by Parvin et al. (2019) for yogurt prepared with apple powder (0.84%). The carbohydrate content of yogurt is influenced by certain ingredients, such as sugar. Greek yogurt fortified with EWSOE, a source of carbohydrates, had a lower content than Greek yogurt added with tamarind pulp (14.7%) and sugar (Silva et al. 2020).

Lactose is the main sugar compound in milk, which is metabolized during fermentation and is crucial for the formation of yogurt gel. The low lactose content in the prepared Greek yogurt is indicative of effective fermentation. Lactose present in whole milk (4.30% ± 0.02%) is metabolized during fermentation (Uduwerella et al. 2017). Of note, lactose is not completely retained during straining for whey removal.

Syneresis has a significant impact on consumer acceptance (Bouaziz et al. 2021). Syneresis values above 39% can lead to microbiological proliferation, affecting the shelf life of yogurt (Aportela-Palacios et al. 2005). Addition of EWSOE might have contributed to the low syneresis of Greek yogurt. Raza et al. (2021) found that dietary fibers of plant origin (as in oats and mango peel) have an absorbent function in the release of whey from yogurt gel.

Yogurt firmness correlates with syneresis; that is, firmer yogurts are less susceptible to syneresis (Kycia et al. 2018, Quintanilha et al. 2021). Thus, low syneresis values are indicative of high yogurt firmness, as observed in the present study. Yogurt firmness and consistency were influenced by EWSOE. The extract increased the resistance of yogurt to deformation, given the presence of fibers and the interactions between polyphenols and milk proteins. Such an interaction leads to the formation of soluble complexes with well-developed structures. A similar behavior was reported by Dabija et al. (2018) in yogurt containing inulin, peas, oats, and wheat and by Hassan et al. (2019) in low-fat yogurt containing cress seed powder.

According to Gavril (Rațu) et al. (2024) the structure and texture of yogurt are formed during the fermentation process and can also be influenced by the addition of hydrocolloids. And possibly the addition of EWSOE in the presence of lactic acid bacteria has influenced the fermentation process, as the carbohydrates present in the flour transformed into lactic acid may have influenced the texture of the yogurt.

The cohesiveness and viscosity index of yogurt were determined. The latter parameter is measured as the area under the negative region of the curve between compression cycles. Higher values of these parameters indicate less resistance to probe removal and reduced deformation before rupture (Garzón et al. 2021). Such behavior is attributed to the interaction between phenolic compounds and proteins. Previous studies have shown that, during storage, the rearrangement of particles, influenced by yogurt cohesiveness and viscosity, may lead to stabilization of casein networks; as a result, the consistency of yogurt is improved (Pan et al. 2019). Hydrogen bonds formed between water and fiber produce a viscous matrix (Özturk et al. 2018).

Sensory assessment of Greek yogurt revealed aroma and texture scores greater than 7. Possibly the solids content contributed to the firmness of the gel, reducing the level of syneresis, characteristic of Greek yogurt, contributing to better acceptance in relation to the texture. Color and aroma were influenced by the addition of mango peel flour; however, despite the evident yellow color of the product, the panelists attributed moderate scores to this parameter (between 6 and 7). Similar findings were reported by Manzoor et al. (2019): yogurt fortified with papaya peel powder was assigned a low color score. The overall appearance of the sample was deemed moderately positive (>7).

According to Marand et al. (2020), the typical aroma of yogurt is acetaldehyde, which is released by the starter culture during the fermentation process. However, with the formation of lactic acid, there is a reduction in this aroma due to post-acidification, as well as degradation of fat and protein. Therefore, the elevated aromatic qualities of Greek yogurt with the addition of water-soluble oat extracts are associated with the volatile compounds present in EWSOE.

Thus, preparation of Greek yogurt with partial replacement of whole milk with EWSOE did not affect product acceptance, indicating that the chemical substances present in EWSOE do not influence the final flavor of the yogurt. In total, 72% of tasters stated that they would buy the product. It should be noted that 66% of the panelists were female and 34% male, predominantly in the 20–30 years age group. Furthermore, 66% of tasters reported that they had a habit of consuming Greek yogurt.

CONCLUSIONS

In conclusion, the incorporation of EWSOE (extracted from mango byproduct) into Greek yogurt has proven to be a promising strategy to improve both its nutritional value and functional properties. This innovative approach resulted in Greek yogurt enriched with hypocholesterolemic fatty acids, increased content of phenolic compounds, adequate lipid and protein content, low lactose content and notable fiber content. The final product not only offers health benefits, but also demonstrates economic viability, presenting strong potential for commercialization in the food industry. Overall, this study highlights the potential of using by-products to create food products of greater nutritional value that meet both consumer preferences and health-conscious markets.

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