e-ISSN: 2687-6698 **Research Article**

Turkish Journal of Analytical Chemistry

www.turkjac.org 2019

TurkJAC

Sensory and physicochemical characteristics of mulberry leathers enriched with sesame, almond, sunflower seeds, coconut, and peanut

Burak Güler[1], Cemalettin Baltacı[1*], Murat Küçük[2], Huri İlyasoğlu[3], Turgut Şahinöz[4], Omer Karpuz[5], Fırat Yılmaz[1], Kağan Kılınç[5]

[1] Gümüşhane University, Faculty of Engineering and Life Sciences, Department of Food Engineering, 29100, Gümüşhane, Türkiye
[2] Karadeniz Technical University, Faculty of Science, Department of Chemistry, 61080, Trabzon, Türkiye
[3] Gümüşhane University, Faculty of Health Sciences, Department of Nutrition and Dietetics, 29100, Gümüşhane, Türkiye
[4] Ordu University, Faculty of Health Sciences, Department of Healthcare Management, Ordu, 52200, Türkiye
[5] Gümüşhane University, Faculty of Engineering and Life Sciences, Department of Genetics and Bioengineering, 29100, Gümüşhane, Türkiye

Abstract

This study aimed to investigate the utilization of sesame, sunflower seed, almond, peanut, and coconut as condiments for the enrichment of mulberry leather, known locally as mulberry pestil. The investigation involved a comprehensive analysis encompassing proximate composition, mineral content, color, physicochemical, and sensory properties. The studied parameters of enriched samples were compared with those of the plain sample. Employing multivariate statistical techniques enabled the differentiation of the enriched leather samples. Consequently, the leather samples were categorized into three groups by the principal component analysis according to their physicochemical and chemical attributes. Strong positive correlations were observed among the studied parameters, as indicated by Spearman's rank correlation coefficients. The physicochemical and chemical properties of enriched samples exhibited substantial variability. The enriched products had abundant calcium, potassium, magnesium, iron, and zinc levels. ML samples, particularly those enriched with ingredients like sesame (1815.19 mg/100g) and coconut (1815.19 mg/100g), are distinguished by their high mineral content. These samples are rich in essential minerals such as calcium (1515.01–1815.19 mg/100g), magnesium (738.53–997.37 mg/100g), and potassium (2121.29–2774.07 mg/100g). The novelty of this study lies in the exploration of diverse condiments to enhance the nutritional profile of mulberry leather, offering a unique approach to fortifying this traditional product. These findings revealed that incorporating these condiments enhanced the nutritional values of leather samples, especially in terms of minerals. 100 g of the enriched mulberry leathers had 68.0-70.7 g of carbohydrate, 4.6-5.7 g of protein, 3.6-5.9 g of fat, and 336-359 kcal of energy value. The enriched products might be proposed to provide nutrients and energy in emergencies, especially for adolescents and people affected by disasters.

Keywords: Almond, coconut, mulberry leather, peanut, sesame, sunflower seeds

1. Introduction

Consumers' demand for healthy foods has increased the interest of the food industry and scientists in developing functional food products. Many food products have been reformulated for fortification with compounds providing health benefits such as vitamins, minerals, and bioactive compounds [1]. Fruit leather is a nutritionally dense product made from fruit juices or fruit pulps that has the potential for fortification. Apple, banana, grape, kiwi, mango, mulberry, and pineapple, and other fruits are used in the production of fruit leathers [2–6].

Fruit leathers, also called fruit sheets, strips, or roll-ups, are enjoyed as snacks or desserts worldwide [7]. In Türkiye, a traditional variety known as pestil is produced as a regional fruit snack. Mulberry is one of the fruits used in pestil (fruit leather) production and has potential beneficial properties such as anti-cholesterol, anti-diabetic, and antioxidant effects because of its bioactive compounds [8]. Various regions of Türkiye are known for producing pestil, a traditional dried fruit product, with Kayseri, Tokat, and Amasya being particularly renowned for their contributions. Each region adds its own unique flavors and methods to the craft. However, Gumushane is distinguished as the center of mulberry leather (ML) production. Gumushane pestil stands out for its use of locally grown mulberries, which provide a distinctive texture and flavor. The region's cool climate and fertile soil enhance the richness

Citation: B. Güler, C. Baltacı, M. Küçük, H. İlyasoğlu, T. Şahinöz, O. Karpuz, F. Yılmaz , K. Kılınç, Sensory and physicochemical characteristics of mulberry leathers enriched with sesame, almond, sunflower seeds, coconut, and peanut, Turk J Anal Chem, 7(1), 2025, 9–21.

***Author of correspondence:** cbaltaci11@gmail.com
Tel: +90 (456) 233 17 93 **Fax:** N/A
Received: June 24, 2024 **Accepted:** August 22, 2024

doi https://doi.org/10.51435/turkjac.1594643

of these mulberries, while the traditional production process results in a thicker, more intensely flavored pestil. Known for its natural sweetness and chewy consistency, Gumushane's pestil is a culinary delight and a symbol of the region's agricultural heritage and craftsmanship. The ingredients of Gumushane pestil are mulberry molasses, honey, milk, wheat flour, and sugar, and condiments such as hazelnuts and walnuts can be used to produce pestil. Gumushane pestil is notable for its unique sensory and physicochemical characteristics, as described in the previous studies [9,10]. It exhibits a distinctively softer and more lustrous texture than other fruit leathers.

The higher nutritional content (mainly carbohydrates) of fruit leather makes it a good energy source. The consumption of fruit leather can contribute to meeting energy requirements, especially for adolescents and communities affected by diseases. Moreover, it helps increase solid fruit intake [11].

This study introduces innovation by utilizing various ingredients such as almonds, sesame, coconut, sunflower seeds, and peanuts as condiments for ML production. This initiative seeks to address a research gap, as previous studies haven't explored the potential of the enrichment of fruit leathers with sesame, almond, sunflower seeds, peanuts, and coconut, especially regarding minerals. This study focuses on a comprehensive investigation of the proximate composition, mineral content, physicochemical properties, color, and sensory characteristics of these enriched fruit leathers.

Enriching ML with condiments like sesame, sunflower seed, almond, peanut, and coconut offers an innovative way to enhance its nutritional value. Locally known as mulberry pestil, ML is a nutrient-dense dried fruit product widely consumed in Türkiye. While previous studies have focused on basic pestil composition or the impact of single ingredients, this study expands on that by examining the effects of multiple condiments on ML's physicochemical, mineral, and sensory properties. Unlike studies that focus on individual ingredients, this work uses multivariate statistical techniques to categorize and differentiate enriched ML samples, providing deeper insights into their physicochemical and chemical attributes.

2. Materials and methods

2.1. Materials

The ingredients used in this study, including mulberry molasses, honey, sugar, wheat flour, coconut, almond, peanut, sesame, and sunflower seeds, were sourced from a local market in Gumushane. The combination of these ingredients, particularly mulberry molasses, coconut, almonds, sunflower seeds, sesame, and peanuts, significantly enhances both the nutritional value and sensory characteristics of MLs. Almonds contribute healthy fats and protein, while sunflower seeds provide antioxidants and essential vitamins. Sesame seeds are rich in calcium and iron, and peanuts are a valuable source of protein and healthy fats. Together, these ingredients work synergistically, enriching the MLs with a diverse range of nutrients, resulting in a more nutritious and flavorful product.

2.2. Chemicals and equipment

The chemicals and solvents used in this study, all analytical or HPLC grade, were procured from Merck (Darmstadt, Germany), ensuring high purity for precise measurements and reliable results. Solvents such as HMF standard (99%), methanol, NaOH, and HNO_3, all analytical or HPLC grade, were used in various stages for the extraction of compounds, preparation of solutions, and analytical measurements. The names of the instruments used for the analyses are provided in the relevant methods.

2.3. Preparation of mulberry leathers

The procedure began by heating a quantity of water (16.20 kg) until it reached its boiling point. Afterwards, a blend of liquid sugar (5.5 kg, with 75% dry matter), honey (4.2 kg), and molasses (0.8 kg) was introduced into the boiling water while being constantly stirred for 20 minutes. The milk (1.3 L) and a tiny amount of water were vigorously mixed with the flour (2.7 kg) in a different bowl. A fraction of this blend was incorporated into the flour following a comprehensive mixing process. When the flour blend was added to the boiling fluid, it developed "herle." The hand refractometer measured the Brix value of the herle as 30%. Once the temperature of the herle reached its boiling point, the heat was subsequently decreased and sustained for 15 minutes. After cooking, the herle was cooled to around 60–65 °C. The herle mixture and drying of the MLs can be seen in Fig. 1A and Fig. 1B.

Concurrently, the exhibition cloth was prepared. The assortment of condiments, including sesame, almond, sunflower seed, peanut, and coconut, weighing 0.9 kg, was added individually to the herle. The herle was uniformly applied onto the surface of the cloth using a spreader, resulting in a consistent and thin layer. Subsequently, the herle was subjected to a drying process at a temperature of 60 °C using airflow for an estimated period of 10 hours. To make it easier to remove the dried fruit leather from the fabric, the back of the cloth was moistened with water. Following a short 40–50 second period, the ML was separated from the cloth and allowed to complete a 2-hour drying procedure. Each type of condiment yielded around 10 kg of fruit leather. The fruit leathers were packaged under room conditions and await further examination. The appearance of the MLs enriched with condiments is shown at Fig. 1C.

Figure 1. A) Herle mixture B) Drying of MLs C) MLs enriched with condiments

2.4. Physicochemical and chemical analyses

The measurement of titration acidity was conducted by utilizing a pH meter by the titration process outlined in the reference method of the Turkish Standard Institute (TS 1125 ISO 750) [12]. The sample was uniformly mixed and weighed (10 g) in a container. A volume of 75 mL of distilled water was added and mixed using a magnetic stirrer. The mixture was titrated using a 0.1 N sodium hydroxide solution for 60 seconds until the pH level reached 8.3. The results of the samples were given in % (m/m) as anhydrous citric acid (ACA). The pH measurement was performed according to the specifications stated in TS 1728 [13].

The color evaluation was conducted by a Minolta Chromameter (CR-400, Konica Minolta Sensing, Inc., Japan), as described in the study by Quek et al. [14]. The color index consists of three parameters: L^* for darkness/whiteness, a^* for greenness/redness, and b^* for blue/yellow. 5 g of sample was placed into the sample container. The device provided direct readings of L^*, a^*, and b^* values. The total color difference was calculated using the formula below

$$\Delta E^*(\text{the total color difference}) = \sqrt{(\Delta L^2 + \Delta a^2 + \Delta b^2)} \quad (1)$$

The total solids content was assessed via the standard method of the TS [15]. A sample of 10 g was weighed in a 100 mL beaker with an accuracy of 0.01 g. Following dissolving, the mixture was put into 200 mL flasks and then filled with water until reaching the designated line. The mixture was subsequently filtered using specialized strainer paper. The solution was measured at a temperature of 20 °C using a refractometer (SOIF WYA-2S digital desktop Abbe refractometer, Soif Optical Instruments, China). The residual substance on the filter paper was desiccated and measured until it attained a constant weight in a drying oven set at 130°C.

100 g of the samples were measured to find the amount of condiment. The condiments were meticulously partitioned using utensils such as knives and scissors. Later, a balance was used to measure each component of the condiment [16]. The thickness of the ML samples was measured with a digital caliper (Robocombo, 0-150 mm).

The moisture contents were tested following the TS standard procedure [17]. A sample weighing 5 g was placed in aluminum cups, which were then heated to a temperature of 103 °C until the weight of the sample remained constant (Apin, Lab Drying Equipment, SH-FDO54, Jaeho Lee Samheung Energy Co. Ltd., South Korea). The results were expressed in g/100 g.

A protein analyzer instrument (Gerhardt, Bonn, Germany) based on the Kjeldahl principle was utilized to determine the crude protein content of the samples, explicitly applying the TS method [18]. The crude protein content was calculated using a factor of 6.25.

The fat content was assessed by applying the TS reference technique [19]. The fat content obtained from the sample milled in the blender was transferred into a 5 g Soxhlet cartridge, which was then sealed with hydrophilic cotton. The collection flask was heated to a constant weight of 103 °C and then weighed as tare. The material was extracted using a Gerhardt classic Soxhlet device (Gerhardt, Bonn, Germany) for 6 hours. The residual solvent in the collection flask was removed entirely. It was placed in an oven set at 103° C, and the amount of crude fat was determined by weighing it to a preset level.

Crude fiber analysis was conducted according to the TS 6932 standard [20]. A sample of 1 g was measured using a 250-milliliter beaker. A volume of 100 mL of a solution containing 1.25% sulfuric acid was added and subjected to heat. Once it reached the boiling point, it was further boiled for 30 minutes. Then, 10 mL of a KOH solution with a concentration of 28% was added, and the mixture continued to heat for 30 minutes. The heated sample was filtered using a preheated glass filter. The item was rinsed with boiling pure water two more times. Ultimately, it was cleansed using acetone. The residues of the glass filter were desiccated in an oven and an automatic drying cabinet at 130°C for an hour. After cooling in the desiccator, the dried substance was weighed. The glass filter weighed beforehand was inserted into the incinerator and subjected to combustion for 30 minutes at a temperature ranging from 550 to

600°C (MF-12, Nuve, Ankara, Türkiye). Following the cooling in the desiccator, the remaining substance was weighed.

The TS reference technique determined the ash content [21,22]. 2.5 g of samples were weighed and placed in a porcelain crucible. The samples were then burned at 550 °C until their weight remained constant (MF-12, Nuve, Ankara, Türkiye). The resultant ash was subjected to analysis of insoluble ash in HCl. The porcelain crucible was filled with 25.0 mL of 10% HCl and then immersed in boiling water for up to 60 minutes. Once it had cooled down, it was passed through the ashless strainer paper. The complete removal of HCl was achieved by rinsing with pure hot water. A volume of 0.1 N $AgNO_3$ solution was introduced into a tube to verify this. The washing process persisted until the absence of any white sediment. The non-dissolvable residue in hydrochloric acid was examined using an alternative technique of TS [21]. The filter paper was placed inside the porcelain crucible and dried. Following exposure to the flame, the ash was transferred to the muffle furnace (MF-12, Nuve, Ankara, Türkiye) at a constant temperature of 525±10 °C. The substance was cooled down and put into a desiccator. Once the weighing temperature was attained, it was weighed.

The samples incinerated in the microwave digestion unit were analyzed for minerals using the ICP-MS device, following the reference protocol [23]. Once the ash samples were dissolved in a solution of 10% nitric acid, they were precisely adjusted to a volume of 50 mL using ultrapure water. The metal ions in the solutions were determined using the ICP-MS equipment (7700, Agilent Technologies, Santa Clara, CA, USA). Before conducting measurements using ICP-MS, the instrument was calibrated using mixed standard solutions containing the metal ions under study [23]. The performance parameters of the ICP-MS method for metal analysis are provided in Table 1. The LOD and LOQ were calculated based on 20 blank samples, with the formulas as follows:

$$LOD\ (Limit\ of\ Detection) = Blank + 3 \times Sd \qquad (2)$$

$$LOQ\ (Limit\ of\ Quantification) = Blank + 10 \times Sd \qquad (3)$$

The quantification of total sugar, glucose, fructose, and sucrose was done with the methodologies described by Yuksel et al. [10]. 5 g of the samples were dissolved in 40 milliliters of distilled water at room temperature. A volume of 25 mL of methanol was added to the mixture, which was then transferred to a volumetric flask. The solution underwent filtration using a membrane filter and was transferred to the vials. HPLC-RID analysis conditions were as follows:

Flow rate: 1.3 mL/min.

Moving phase: Acetonitrile / water (80:20) volumetric

Column temperature: 30 °C ± 1 °C

Injection volume : 10 µl

Device : HPLC-RID (Thermo Finnigan HPLC)

Peaks were identified in both the standards and samples, and the areas of these peaks were quantified. A linear calibration graph was constructed to display peak areas measured in micrograms per milliliter. The data collection and calculating method determined glucose, fructose, and sucrose percentages.

The hydroxymethylfurfural (HMF) quantification was conducted using the method of Baltaci and Aksit [24]. 5 g of the sample was placed into a 50 mL container. Then, 25 mL of pure water was added to dissolve the material. To prevent the degradation of HMF, 0.5 mL of Carrez I and 0.5 mL of Carrez II were added. The sample, which was prepared using a funnel, was filtered. The solution was transferred into vials, filtered via a 0.45-micron filter, and injected into the prepared HPLC system (Thermo Finnigan HPLC, Thermo Electron, San Jose, CA). The calibration curve was prepared using standards of HMF at concentrations of 1.0, 2.0, 4.0, 8.0, and 12.0 mg/L. The performance parameters of the HPLC method for HMF analysis are as follows: The linear range is 1.0–12 µg/g, with a calibration curve equation of $y=7036x-0.30$ and an R^2 value of 0.999. The limit of detection (LOD) is 0.01 µg/g, and the Limit of Quantification (LOQ) is 0.03 µg/g. Precision is demonstrated by a relative standard deviation for repeatability (RSD_r) of 1.58%, which is below the Horwitz value, and for reproducibility (RSD_R), it is 2.56%, also below the Horwitz value. The recovery rates for HMF analysis are 98.83% at 25 µg/g, 97.18% at 50 µg/g, and 99.39% at 75 µg/g.

2.5. Sensory analysis

The analysts were comprised of 10 individuals who were well-educated (students of the Department of Food Engineering). The panel was evenly divided between 5 males and 5 females, ages 18 to 24, and all members were nonsmokers. An evaluation assessment of fruit leather was completed, examining its color, taste, smell, and appearance. The sensory scores, ranging from 1 to 4, were derived from the analysis [16].

2.6. Statistical analysis

Agglomerative hierarchical clustering (AHC), preference mapping (PREMAP), and principal component analysis (PCA) were executed by employing the Microsoft Excel program with the assistance of XLSTAT (Addinsoft (2024), XLSTAT statistical and data analysis solution, New York, USA, https://www.xlstat.com).

Table 1. Performance parameters of the method in ICP-MS for metals analysis

No	Mineral	Calibration curve	R2	RSD%		Linearity (µg/mL)	LOD/LOQ (µg/mL)	Recover (%)	
				RSDr	RSDR			Intra-day	Inter-day
1	Na	y=-9066924.3x+244348.2	0.998	0.52	0.71	0.5-25	0.03/0.09	100.11	100.83
2	Mg	y=-2307216.6x+16968.9	0.995	1.03	1.06	0.3-9	0.05/0.15	99.63	100.16
3	Al	y=12250x+12162.9	0.971	0.94	2.08	0.5-10	0.7/2.22	99.68	100.68
4	Ca	y=338057x+27399.8	0.999	0.82	1.61	5-80	0.7/0.21	100.10	99.47
5	K	y=2679658x+300146.5	0.998	0.75	1.23	5-100	0.02/0.07	99.69	100.41
6	Cr	y=19224.9x+2095.1	0.957	0.77	1.44	0.01-0.10	0.20/0.60	99.72	100.55
7	Mn	y=13370.8x+3787.2	0.999	1.09	2.15	0.01-0.25	0.005/0.015	100.24	100.45
8	Fe	y=16734.0x+99314	0.997	1.21	1.82	0.1-5	0.12/0.40	99.63	100.77
9	Co	y=27170.7x+380.0	0.995	1.51	2.16	0.01-1.0	0.02/0.08	100.00	99.67
10	Ni	y=6903.2x+3978.1	0.996	0.58	2.09	0.01-0.5	0.02/0.06	100.02	99.88
11	Cu	y=18008.0x+7625.2	0.999	1.17	2.41	0.1-0.4	0.02/0.06	99.70	99.51
12	Zn	y=4102.8x+134853.9	0.999	0.64	1.31	0.01-30	0.06/0.22	99.81	100.79
13	As	y=2608.0x+52.3	0.999	1.49	2.21	0.001-0.02	0.002./0.006	99.83	99.97
14	Pd	y=15301x+6444.2	0.999	0.98	1.23	0.2-10	0.01/0.03	100.32	100.68
15	Ag	y=-47157.7x+7158.4	0.999	0.61	1.48	0.02-0.16	0.01/0.03	100.13	100.12
16	Cd	y=11116x+779.4	0.999	0.77	1.93	0.01-5.0	0.02/0.06	99.22	99.98
17	Sn	y=272.1x+149.9	0.999	1.23	1.12	0.01-0.5	0.02/0.06	100.15	100.42
18	Ba	y=13516.8×+6324.7	0.998	1.08	1.19	0.05-0.5	0.01/0.03	100.06	100.72
19	Hg	y=85457.1x+2040.2	0.998	0.83	1.11	0.1-5	0.03/0.09	100.09	99.67
20	Pb	y=53700.4x+42830.9	0.999	1.08	1.19	1-50	0.7/2.20	99.23	100.45
21	P	y=101446.1x+4877.1	0.996	0.82	1.11	0.1-5	0.2/0.6	98.12	99.77

3. Results and Discussion

3.1. Physicochemical properties

Table 2 presents the findings about physicochemical parameters. Significant differences in the physicochemical parameters were observed among the samples ($p < 0.05$).

One of the significant physical properties is the thickness of fruit leather, which plays a dual role as an edible film. The thicknesses of MLs ranged from 1.31 mm to 2.21 mm. According to Yıldız [9], the MLs exhibited a thickness value ranging from 0.80 mm to 1.25 mm. Yıldız and Boyracı [25] determined the thickness of pestil samples, varying from 0.92 mm to 1.12 mm. Compared with the previous studies, the ML with the condiments displayed notably greater thickness values.

Addressing acidity and pH, the MLs exhibited acidity values of 0.12% and 0.19%, with pH values of 6.05 and 6.13, respectively. The plan ML had a lower acidity value than the ML with condiments. The acidity of fruit leather mainly depends on the fruit pulp or juice used in the production. Yildiz [9] reported the ML acidity values of 0.14% and 0.15%. In another study, Karaoğlu et al. [26] determined the acidity and pH values of MLs, ranging from 0.40% to 0.73% and 5.67 to 5.81, respectively. According to Tontul and Topuz [27], the pomegranate leathers exhibited pH values varying from 3.61 to 3.68.

3.2. Color properties

The color attributes of the leather samples displayed significant differences with a confidence level of 95% ($P < 0.05$) (Table 3). The color analyses were elucidated using PCA at a rate of 99.18% (Fig. 2). The color differences (ΔE*ab) were found to be more significant based on the PCA loadings and scores. The MLs enriched with coconut and sunflower seeds showed a lighter hue. Conversely, the plain ML had a more intense hue. Different condiments in the fruit leather formulations greatly impacted the values of *L**, *a**, *b**, and ΔE*ab. The variations in the MLs' color values could arise from using different condiments during production. The color of fruit leather products can be modified through baking and drying methods employed during manufacturing. Suna and Özkan-Karabacak [28] determined the *L**, *a**, and *b** values of the ML samples dried with differing methods, ranging from 28.57 to 35.42, from 4.44 to 8.15, and from 11.15 to 19.06, respectively. According to an investigation on the effects of sugars and cooking time on the color properties of ML, the *L**, *a**, and *b** values varied from 31.64 to 35.86, from 5.33 to 9.41, and from 0.63 to 8.55, respectively [29]. Except for the plain fruit leather samples, the *ΔE**ab analysis revealed statistically noticeable variations among the samples ($P < 0.05$), as demonstrated in Table 3.

3.3. Proximate composition

The proximate composition of the ML samples is presented in Table 2. The moisture content of the ML samples ranged from 15.49% to 19.43%. Moisture content is a pivotal characteristic of fruit leather and should be kept lower to ensure extended product storage without deterioration. The moisture content of fruit leather varies depending on formulation and drying process. The moisture content of apricot, grape, and MLs procured from the local market was determined to range from 11.8% to 18.3% [30]. An investigation of the development of kiwi leather using different hydrocolloids showed

Table 2. Physicochemical and chemical properties of MLs

Sample	Plain ML	Almond-added ML	Peanut-added ML	Sunflower seed-added ML	Sesame-added ML	Coconut-added ML
Thickness (mm)/diameter	1.31±0.10^{c}	2.15±0.10^{a}	2.21±0.05^{a}	2.21±0.07^{a}	1.63±0.13^{b}	1.58±0.09^{b}
Condiment (g/100 g)	0.01±0.01^{b}	10.69±0.06^{a}	10.72±0.17^{a}	10.73±0.17^{a}	10.77±0.12^{a}	10.77±0.21^{a}
Total solids (g/100 g)	84.48±0.07^{a}	82.71±0.17^{b}	82.66±0.28^{b}	82.12±0.50^{b}	79.69±0.33^{c}	79.49±0.48^{c}
Moisture (g/100 g)	15.49±0.01^{d}	16.79±0.01^{c}	16.87±0.01^{c}	17.12±0.02^{b}	19.43±0.03^{a}	19.39±0.02^{a}
Acidity (ACAeq.) (g/100 g)	0.12±0.01^{c}	0.19±0.01^{a}	0.16±0.01^{b}	0.16±0.01^{b}	0.18±0.01^{a}	0.19±0.01^{a}
pH	6.13±0.04^{a}	6.05±0.03^{b}	6.07±0.02^{b}	6.07±0.02^{b}	6.07±0.02^{b}	6.11±0.02^{a}
HMF (mg/kg)	3.45±0.14^{a}	3.08±0.08^{b}	3.17±0.07^{b}	3.21±0.06^{b}	1.75±0.10^{c}	1.69±0.10^{c}
Protein (g/100 g)	6.75±0.15^{a}	5.70±0.07^{b}	5.57±0.11^{b}	5.70±0.06^{b}	4.70±0.12^{c}	4.63±0.15^{c}
Total ash (g/100 g)	0.44±0.02^{c}	0.65±0.03^{ab}	0.66±0.03^{b}	0.67±0.02^{b}	0.77±0.03^{a}	0.77±0.02^{a}
10% HCl Insoluble ash (g/100 g)	0.14±0.02^{c}	0.14±0.01^{c}	0.14±0.01^{c}	0.15±0.01^{bc}	0.18±0.01^{a}	0.17±0.02^{ab}
Total sugar (g/100 g)	39.01±0.01^{a}	39.28±0.01^{a}	39.28±0.02^{a}	39.28±0.02^{a}	39.47±0.03^{a}	39.47±0.51^{a}
Glucose (g/100 g)	10.35±0.10^{c}	10.67±0.02^{b}	10.78±0.10^{ab}	10.91±0.06^{a}	10.78±0.11^{ab}	10.70±0.12^{b}
Fructose (g/100 g)	10.31±0.04^{d}	10.54±0.07^{c}	10.63±0.06^{bc}	10.75±0.10^{ab}	10.86±0.12^{a}	10.88±0.01^{a}
Sucrose (g/100 g)	18.65±0.04^{a}	18.27±0.12^{b}	18.41±0.08^{b}	18.30±0.06^{b}	18.40±0.07^{b}	18.38±0.14^{b}
Cellulose (g/100 g)	0.36±0.03^{e}	0.75±0.03^{d}	0.84±0.03^{c}	0.75±0.03^{b}	1.32±0.03^{b}	1.44±0.02^{a}
Total fat (g/100)	0.23±0.02^{e}	5.45±0.06^{b}	5.90±0.09^{a}	5.84±0.04^{ab}	5.76±0.13^{d}	3.63±0.08^{d}
Total mineral (g/100 g)	0.46±0.05^{c}	0.67±0.04^{ab}	0.61±0.01^{b}	0.70±0.05^{a}	0.65±0.04^{ab}	0.70±0.03^{a}
Carbohydrate (g/100 g)	76.62±0.14^{a}	70.66±0.07^{b}	70.16±0.12^{c}	69.93±0.15^{c}	68.03±0.30^{d}	70.14±0.12^{c}
Energy (kcal/100 g)	336.67±0.12^{d}	356.7±0.41^{b}	358.57±0.39^{a}	357.27±0.10^{b}	346.68±0.48^{c}	336.04±0.35^{e}

Note: Results are presented as means ± standard deviations. Different letters (a-e) in the same lines are significantly (P <0.05) different.

that the moisture content of the leather samples varied from 17.45% to 22.00% [2]. Our study's results fell within the range of 79.49–84.48% concerning the total solids content of the ML samples. These values were comparable with the values reported by Çağındı & Otleş [30] and Bayram [31] for apricot, grape, and MLs.

The primary macronutrient in the ML samples was carbohydrate, ranging from 68.03 to 76.62 g/100 g. The protein and fat contents of the MLs varied from 4.63 to 6.75 g/100 g and 0.23 to 5.90 g/100 g, respectively. Legal regulations do not stipulate a specific limit for the macronutrients. As shown in Table 4, there are significant correlations between the quantity of condiments and the macronutrients ($p < 0.05$). A significant negative correlation for both carbohydrate ($r = -0.95$) and protein ($r = -0.78$) and a significant positive correlation for fat ($r = 0.92$) were observed. The plain ML contained the highest contents of carbohydrates (76.62 g/100g) and protein (6.75 g/100g), while the peanut-added ML had the highest fat content (5.90 g/100g). The levels of macronutrients in fruit leather depend on the fruit and other ingredients used in the production.

According to Yıldız [9], the plain ML had protein (4.34%) and fat (0.98%). In another study, the carbohydrate, protein, and fat contents of apricot, grape, and MLs were reported to range from 73.7% to 82.4%, from 3% to 6%, and from 0.2% to 3.4%, respectively [30]. Sarma et al. [1] determined that the banana leather contained carbohydrates (56.04%), protein (6.23), and fat (0.18%).

The energy value of the MLs ranged from 336.04 to 358.57 kcal/100 g (Table 2). The plain ML had the lowest energy value, whereas the peanut-added ML exhibited the highest. A 100-gram portion of MLs accounts for approximately 17% of an adult's daily reference intake (RI) based on a 2000-calorie diet. Due to their higher carbohydrate contents and energy values, the MLs can serve as wholesome supplementary meals, snack options, and rapid energy sources. Moreover, they can be alternative options for the high-energy foods needed in short-term nutrition emergency services in case of disasters.

Table 3. Color measurement of MLs

Sample	L*	a*	b*	ΔE*ab
Plain ML	41.33±1.23 d	12.58±1.06 a	21.44±1.13 a	0.00f
Sesame-added ML	43.49±0.53 c	9.63±0.14 b	18.95±0.84 b	3.81±0.33 e
Almond-added ML	43.67±0.89 c	7.18±0.05 d	13.89±0.29 d	8.96±0.33 c
Coconut-added ML	47.63±0.59 a	6.03±0.13 e	12.09±0.26 e	12.41±0.38 a
Peanut-added ML	43.32±1.19 c	7.81±0.22 c	15.97±0.31 c	7.98 ±0.33 d
Sunflower seed-added ML	45.93±0.26 b	6.80±0.34 d	11.68±0.75 e	11.62±0.16 b

The data are shown as the mean of three determinations, accompanied by the associated ± standard deviation. A variety of letters (a-f) in the same column indicate significant differences, attaining statistical significance at the 95% level ($P < 0.05$). In this context, the symbol "L*" represents the degree of darkness or lightness, where a value of 0 corresponds to black and a value of 100 corresponds to white. Similarly, the symbol "a*" represents the absence of greenness (-a) and the presence of redness (+a), while the symbol "b*" indicates the absence of blueness (-b) and the presence of yellowness (+b).

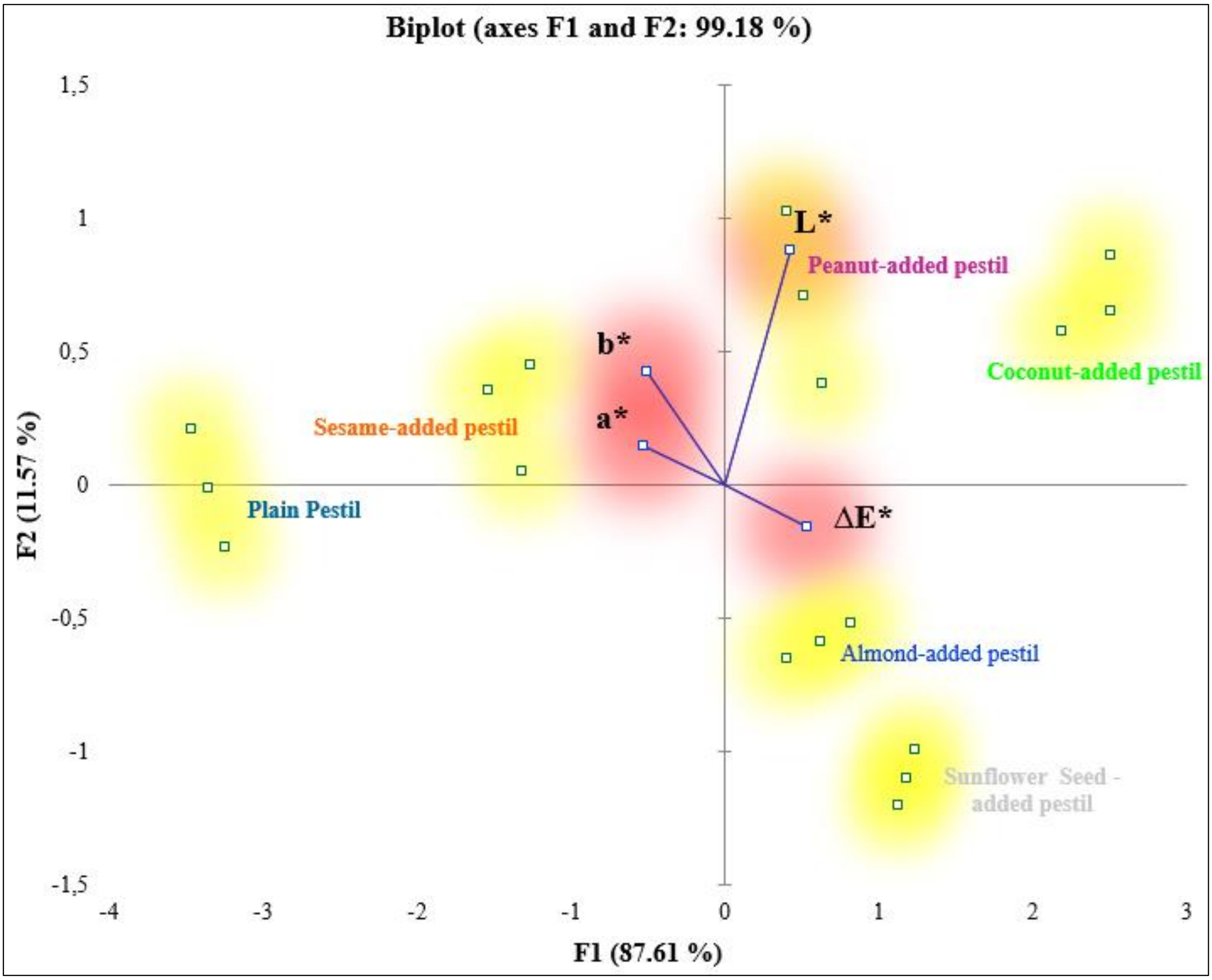

Figure 2. PCA analysis of the color properties of the MLs with different condiments

The MLs showed no significant differences in total sugar content ($p > 0.05$). The total sugar content of ML was not explicitly specified in the TS 12677 [16] ML standard. The total sugar (39.00-39.50%), glucose (10.30-10.90%), and fructose (10.30-10.90%) levels of the ML samples were found to be lower than results of the previous studies. Bayram [31] reported that the MLs contained total sugar levels ranging from 47.60% to 59.20%, glucose levels from 11.00% to 15.80%, and fructose levels from 7.10% to 9.20%. Yildiz [9] determined that MLs had sugar content ranging from 51.30% to 62.50%. The lower values in our study could be attributed to the differences in the types and levels of sugars and honey used in the formulation of MLs.

There is no prescribed cellulose limit for fruit leather within any legal regulations. As indicated in Table 4, there is a noticeable positive correlation between cellulose and condiment content ($r = 0.67$). Among the ML samples, sesame and coconut exhibit elevated cellulose content. Bayram [31] examined the MLs with condiments such as hazelnut and walnut, revealing varying cellulose ratios of 2.0% to 2.20%. These values were higher than those found in our study, which might be attributed to the choice of ingredients.

The ash content of the MLs ranged from 0.44% to 0.77%. As shown in Table 3, strong positive correlations indicate that when one variable increases, the other tends to increase as well. For example, protein and total ash ($r = 0.97$) and glucose and fructose ($r = 0.88$) both show a simultaneous increase, suggesting that these components are closely related and tend to vary together. On the other hand, strong negative correlations indicate an inverse relationship, where an increase in one variable leads to a decrease in another. For instance, acidity and protein ($r = -0.95$) and moisture and protein ($r = -0.97$) demonstrate such relationships, implying that higher acidity or moisture content may result in lower protein levels. These correlations provide valuable insights into how various chemical and physicochemical properties of the samples interact, helping to better understand the underlying dynamics between these factors.

Table 4. Correlation matrix for the physicochemical and chemical parameters of products

Variables	Thickness	Amount of Condiment	Total Solids	Moisture	Acidity ben	pH	HMF	Protein	Total Ash	% 10 HCl Insoluble	Total Sugar	Glucose	Fructose	Sucrose	Cellulose	Total Fat	Carbohydrate	Energy	Total Mineral
Thickness	**1.00**	**0.66**	0.07	-0.16	0.35	**-0.78**	0.33	-0.07	0.27	-0.38	0.15	**0.65**	0.18	**-0.62**	-0.08	**0.79**	**-0.50**	**0.93**	**0.50**
Amount of Condiment		**1.00**	**-0.68**	**0.62**	**0.86**	**-0.67**	-0.45	**-0.78**	**0.88**	0.25	**0.84**	**0.83**	**0.77**	**-0.78**	**0.67**	**0.92**	**-0.95**	**0.56**	**0.86**
Total Solids			**1.00**	**-0.98**	**-0.73**	0.10	**0.92**	**0.95**	**-0.92**	**-0.72**	**-0.96**	**-0.49**	**-0.89**	0.38	**-0.97**	-0.46	**0.79**	0.17	**-0.65**
Moisture				**1.00**	**0.71**	-0.09	**-0.97**	**-0.96**	**0.89**	**0.75**	**0.95**	0.44	**0.87**	-0.32	**0.98**	0.39	**-0.74**	-0.25	**0.60**
Acidity (ACA eq.)					**1.00**	**-0.52**	**-0.62**	**-0.80**	**0.85**	0.39	**0.85**	**0.62**	**0.71**	**-0.74**	**0.75**	**0.69**	**-0.82**	0.25	**0.81**
pH						**1.00**	-0.04	0.28	-0.43	0.23	-0.34	**-0.64**	-0.24	**0.64**	-0.12	**-0.79**	**0.61**	**-0.78**	**-0.50**
HMF							**1.00**	**0.89**	**-0.78**	**-0.78**	**-0.86**	-0.25	**-0.78**	0.16	**-0.95**	-0.20	**0.59**	0.43	-0.46
Protein								**1.00**	**-0.95**	**-0.62**	**-0.98**	**-0.55**	**-0.88**	**0.47**	**-0.97**	**-0.57**	**0.84**	0.04	**-0.69**
Total Ash									**1.00**	**0.53**	**0.97**	**0.68**	**0.91**	**-0.62**	**0.91**	**0.71**	**-0.92**	0.15	**0.77**
% 10 HCl Insol. Ash										**1.00**	**0.62**	0.13	**0.64**	0.01	**0.70**	0.10	-0.42	-0.39	0.29
Total Sugar											**1.00**	**0.63**	**0.91**	**-0.54**	**0.96**	**0.65**	**-0.90**	0.05	**0.76**
Glucose												**1.00**	**0.67**	**-0.77**	0.46	**0.85**	**-0.82**	**0.60**	**0.78**
Fructose													**1.00**	-0.43	**0.88**	**0.60**	**-0.84**	0.05	**0.72**
Sucrose														**1.00**	-0.35	**-0.74**	**0.68**	**-0.56**	**-0.75**
Cellulose															**1.00**	0.43	**-0.76**	-0.20	**0.62**
Total Fat																**1.00**	**-0.91**	**0.79**	**0.71**
Carbohydrate																	**1.00**	-0.46	**-0.79**
Energy																		**1.00**	0.35
Total Mineral																			**1.00**

Note: Values in bold are different from 0 with a significance level alpha=0.05. Significant correlations are displayed **in bold**. Correlation coefficients vary **-1 and 1**.

The closer is to 1 or -1. stronger is the link between two variables. **Negative** values indicate negative correlation. and **positive** values indicate positive correlation.

Values close **zero** reflect the absence of correlation.

The ML samples incorporating coconut and sesame yielded higher values than the others, whereas the plain leather exhibited a lower value. Bayram [31] reported that the ash content was 0.35%-0.40% and 0.45%-0.75% for the plain ML and the ML with hazelnut and walnut, respectively. According to a study using different flours in the production of ML, the ash contents of ML samples ranged from 0.66 g/100 g to 1.71 g/100 g [10].

3.4. Mineral content

Minerals collaborate synergistically with vitamins in our bodies, optimizing the effective utilization of these vitamins and other essential nutrients. A comprehensive evaluation of 21 minerals was undertaken in the ML samples, and these results are provided in Table 6. All condiment-added MLs displayed significant sodium, potassium, calcium, phosphorus, magnesium, manganese, iron, and zinc abundances. Additionally, other elements, including copper and nickel, were detected. Notably, metals such as arsenic (As), lead (Pb), cadmium (Cd), and mercury (Hg) were detected below the limit of quantification (LOQ) by the maximum residue limits regulated by Turkish Food Codex regulations on contaminants. A study highlighted the elevated presence of potassium, calcium, and zinc in apricot fruit leather, whereas mulberry fruit leather exhibited a higher amount of magnesium [30].

As indicated in Table 4, there is a strong positive correlation between the amounts of condiments and total mineral content (r = 0.86). Minerals like calcium, phosphorus, magnesium, manganese, and zinc were more pronounced in MLs enriched with condiments than the plain ones, indicating that incorporating condiments enhanced the nutritional values of MLs. The peanut-added ML had the lowest sodium. A reduction in the sodium intake and an increase in the potassium intake are recommended for a healthy diet. The peanut-added sample might have superiority over other MLs since the incorporation of peanuts decreased sodium and potassium content.

3.5. HMF levels

HMF is an indicator of heat treatment in foods and is regulated by standards. For example, mulberry fruit leather's maximum allowable HMF content is 50 mg/kg [16]. In our examination, which spanned six MLs, the HMF concentrations ranged from 1.69 mg/kg to 3.45 mg/kg, with plain ML containing the highest levels and coconut-added ML having the lowest. HMF content is extensively used to indicate Maillard reactions and browning in several foods, including honey and molasses [32]. The gel structure known as "herle," the initial phase of fruit leather production, is formed by boiling a blend of fruit pulp or juice, flour, sugar, honey, and water for approximately two hours. The process conditions for boiling treatment in the production of herle can impact the HMF content. A study comparing HMF formation resulting from maintaining herle at

Table 5. The loadings and the scores of the first five rotated principal components

The Loadings	F1	F2	F3	F4	F5
Thickness (mm)	0.352	0.894	0.111	0.041	-0.043
Amount of condiment (g/100 g)	0.927	0.341	0.006	-0.011	-0.014
Total solids (g/100 g)	-0.887	0.428	-0.023	-0.010	0.063
Moisture (g/100 g)	0.860	-0.499	0.014	-0.047	-0.045
Acidity (ACA eq.) (g/100 g)	0.888	0.074	-0.306	-0.112	0.219
pH	-0.489	-0.721	-0.008	0.375	-0.072
HMF (mg/kg)	-0.738	0.651	0.027	0.125	0.004
Protein (g/100 g)	-0.934	0.290	0.016	0.129	0.074
Total Ash (g/100 g)	0.978	-0.093	-0.007	-0.075	-0.066
% 10 HCl insol. ash (g/100 g)	0.525	-0.653	0.270	0.201	0.418
Total sugar (g/100 g)	0.973	-0.211	-0.002	-0.071	-0.025
Glucose (g/100 g)	0.767	0.456	0.058	0.288	-0.155
Fructose (g/100 g)	0.907	-0.207	0.184	0.173	-0.128
Sucrose (g/100 g)	-0.676	-0.505	0.427	-0.142	-0.103
Cellulose (g/100 g)	0.879	-0.448	-0.016	-0.081	-0.091
Total fat (g/100)	0.782	0.570	0.211	-0.045	0.051
Carbohydrate (g/100 g)	-0.961	-0.185	-0.170	0.039	-0.020
Energy (kcal/100 g)	0.252	0.930	0.220	-0.014	0.088
Total mineral (g/100 g)	0.845	0.215	-0.237	0.275	0.000
The Scores	**F1**	**F2**	**F3**	**F4**	**F5**
Plain pestil	-7.179	-1.686	0.892	0.014	0.014
Almond-added pestil	0.159	2.247	-0.869	-0.526	0.571
Peanut-added pestil	-0.060	2.009	0.698	-0.326	-0.390
Sunflower seed-added pestil	0.792	2.085	0.227	1.051	-0.145
Sesame-added pestil	3.347	-1.700	0.667	-0.460	0.263
Coconut-added pestil	2.941	-2.955	-0.703	0.247	-0.313

temperatures of 60, 70, 80, 90, 100, and 110 °C for 2, 4, and 6 hours demonstrated a substantial increase in HMF with a higher temperature and longer duration. It is recommended that the temperature not exceed 90 °C during fruit leather production [33]. Moreover, studies suggest that drying can significantly influence HMF formation [27,31]. Previously reported HMF concentrations were 27.94 mg/kg for plain ML, 21.42 mg/kg for hazelnut-added ML, and 18.15 mg/kg for walnut-added ML [9]. Yildiz and Boyraci [25] indicated that hazelnut- and walnut-added pestil contained HMF levels of 17.26 mg/kg and 15.24 mg/kg, respectively. In another study, the HMF content of MLs ranged from 1.42 mg/kg to 6.60 mg/kg [10].

3.6. Sensorial properties

The evaluation of sensory attributes plays a crucial part in determining the overall quality of food. Evaluating and discussing traditional foods' taste and general quality with consumers is essential [34]. The sensory analysis results for six samples of MLs were analyzed using several analytical techniques, including PCA, AHC, and PREMAP (Fig. 3A and Fig. 3B). The AHC analysis led to the classifying of sensory outcomes into seven separate groups (Fig. 3B). The PREMAP technique efficiently gathered 81% of the sensory analysis data by utilizing PCA and AHC analyses. The fourth group displayed the highest level of approval in the sensory evaluations. This group primarily consisted of fruit leather samples enriched with coconut, sesame, and almond. This group, located in the red zone on the PREMAP, received the highest ratings regarding appearance, taste, and smell. Their preference ratings ranged from 80% to 100%. The fifth group, consisting mainly of fruit leather enriched with sunflower seeds and peanuts, received the second-highest scores for color, taste, and smell. The preference scores for this group varied between 60% and 80%. The preference ranges for plain, sesame, and almond fruit leathers were 20% to 40% in the third and sixth categories. The panelists provided scores similar to those of the first, second, and seventh groups, suggesting a slight preference for the fruit leather samples. Their preference scores varied between 0% and 20%. The PREMAP examination calculated the scores for coconut, sesame, almond, sunflower seed, peanut, and plain fruit leather. The preference map indicated that most panelists, ranging from 60% to 80%, favored color, taste, and smell. On the other hand, a minority of 20% to 40% of the panelists leaned towards appearance (Fig. 3A).

3.7. Principal Component Analysis (PCA)

The score plot (Fig. 4) visually represents the positioning of ML samples within a multivariate space defined by the first two principal components (PCs). The scores are distributed across four quadrants, highlighting distinct separations between the samples based on the specific physical and chemical attributes examined. Notably, the plot clearly differentiates between the plain and enriched MLs, with three distinct groups emerging. The red cluster represents the plain pestil, while the blue cluster includes peanut-added pestil, sunflower seed-added pestil, and almond-added pestil. The yellow cluster consists of sesame-added pestil and coconut-

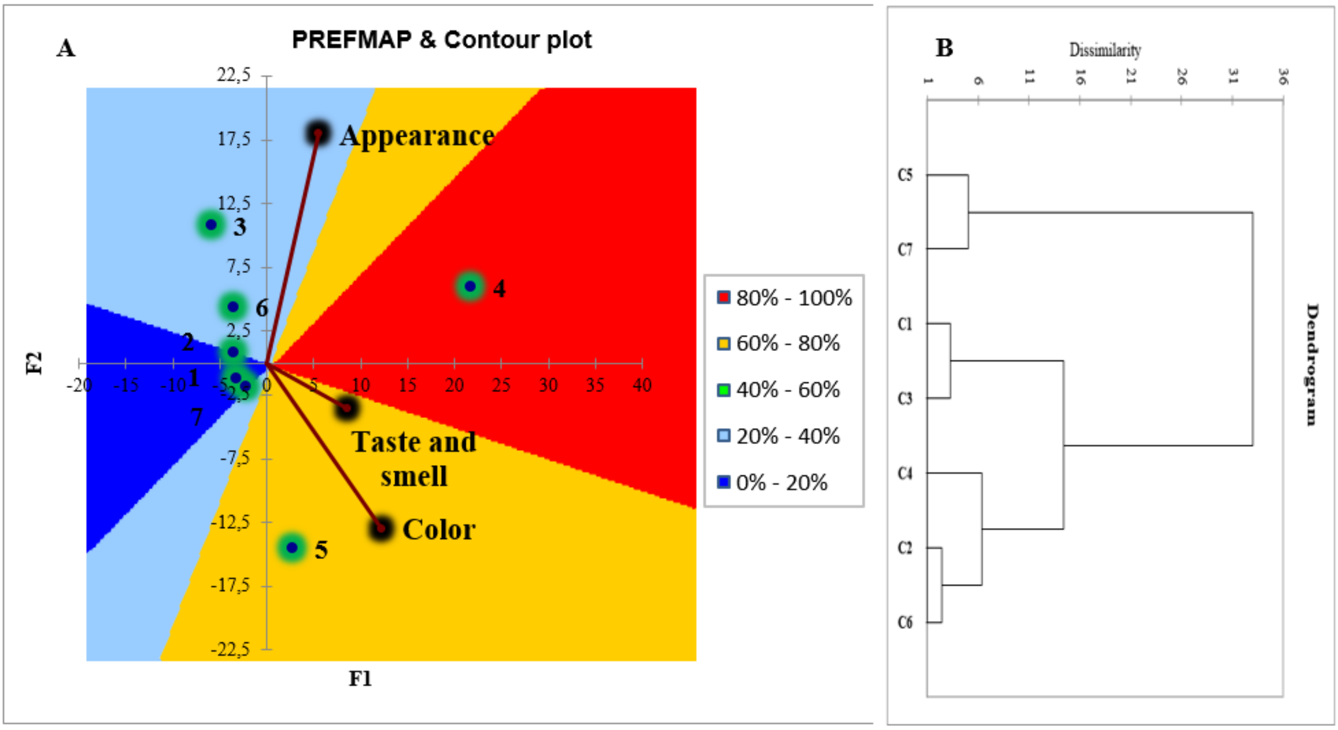

Figure 3. A) Preference mapping (PREMAP) B) Agglomerative hierarchical clustering (AHC) values of panelists

added pestil. Together, the first two principal components (F1 and F2) explain 89.06% of the variance in the data. The score plot (Fig. 4) and the data in Table 4 strongly support each other.

The ML samples may be classified into three categories according to the physicochemical and chemical analysis results. The first category comprises plain fruit leather, while sesame and coconut fruit leathers comprise the second category. The third category includes sunflower seeds, almonds, and peanuts. Within the first group, the plain ML sample in the bottom left segment of the plot exhibits the highest levels of sucrose, carbohydrates, pH, protein, total solids, and HMF content while displaying lower levels in other analytical components. Using the PC1-PC2 plane to compare groups shows that the second group (almond, peanut, and sunflower seed-added MLs) has higher energy, total fat, glucose, and thickness. The third ML group (coconut and sesame-added) showcases elevated levels of cellulose, total ash, total sugar,moisture, insoluble ash in HCl, acidity, and fructose based on the PC1-PC2 axis.

Table 6. Mineral analysis results of plain and condiment added MLs

	Plain ML	Almond-added ML	Sunflower Seed-added ML	Peanut-added ML	Sesame-added ML	Coconut-added ML
Na	700.79±15.37 ^{b}	630.12 ±13.68 ^{bc}	686.37±18.96 ^{b}	467.82±11.73 ^{c}	886.9±12.64 ^{a}	952.34±13.18 ^{a}
Mg	415.01±16.05 ^{c}	700.58±17.24 ^{b}	997.37±19.92 ^{a}	606.82±10.73 ^{bc}	738.53±15.16 ^{ab}	773.69±16.41 ^{ab}
Al	58.15±3.99 ^{a}	52.09±9.09 ^{ab}	22.41±1.36 ^{bc}	38.67 ±8.03 ^{abc}	42.98±5.63 ^{abc}	16.70±1.41 ^{c}
Ca	888.04±4.97 ^{c}	1277.95±12.32 ^{b}	1350.17±12.25 ^{b}	1425.16±25.65 ^{b}	1515.01±12.82 ^{ab}	1815.19±10.24 ^{a}
K	2127.72±14.97 ^{b}	2745.34±11.31 ^{a}	2774.07±15.78 ^{a}	2378.32±16.19 ^{ab}	2121.29±17.09 ^{b}	2526.59±16.61 ^{ab}
Cr	1.75±0.43 ^{b}	4.58±1.84 ^{a}	2.18±0.73 ^{b}	2.03±1.11 ^{b}	2.04±0.13 ^{b}	1.50±0.27 ^{b}
Mn	54.15±3.88 ^{c}	74.19±4.46 ^{ab}	90.81±7.99 ^{a}	75.75±13.61 ^{ab}	82.58±1.23 ^{ab}	69.68±10.46 ^{bc}
Fe	195.84±22.53 ^{a}	304.53±52.23 ^{a}	283.27±14.62 ^{a}	273.97±129.88 ^{a}	349.45±175.44 ^{a}	258.82±6.23 ^{a}
Co	0.24±0.03 ^{b}	0.28±0.02 ^{b}	0.33±0.04 ^{b}	0.27±0.04 ^{b}	0.53±0.07 ^{a}	0.61±0.12 ^{a}
Ni	55.05±2.64 ^{a}	23.00±3.21 ^{b}	21.34±2.92 ^{b}	15.60±4.26 ^{b}	18.49±2.38 ^{b}	29.28±4.97 ^{b}
Cu	11.77±0.33 ^{c}	20.15±4.42 ^{bc}	50.61±8.41 ^{a}	18.14±1.65 ^{bc}	29.52±3.75 ^{b}	33.10±6.97 ^{b}
Zn	284.17±11.82 ^{b}	534.39±15.35 ^{a}	390.93±15.71 ^{ab}	395.16±12.31 ^{ab}	350.23±14.01 ^{b}	276.94±9.79 ^{b}
As	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Pd	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Ag	1.16±0.08 ^{b}	1.33±0.03 ^{b}	1.14±0.06 ^{b}	1.60±0.17 ^{a}	1.13±0.14 ^{b}	1.10±0.05 ^{b}
Cd	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Sn	0.16±0.02 ^{a}	0.17±0.02 ^{a}	0.14±0.01 ^{a}	0.14±0.03 ^{a}	0.13±0.01 ^{a}	0.14±0.01 ^{a}
Ba	15.63±3.56 ^{b}	34.18±6.59 ^{a}	15.33±3.82 ^{b}	19.81±1.81 ^{b}	12.13±2.04 ^{b}	14.12±0.18 ^{b}
Hg	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Pb	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
P	250.78±4.97 ^{e}	295.54±6.05 ^{d}	351.48±11.19 ^{a}	327.05±11.17 ^{b}	320.50±11.11 ^{c}	320.52±12.30 ^{c}

Results are presented as means ± standard deviations. Results of minerals were expressed as mg/kg. Different letters (a-f) in the same lines are significantly different ($p<0.05$). LOQ=0.01 mg/kg

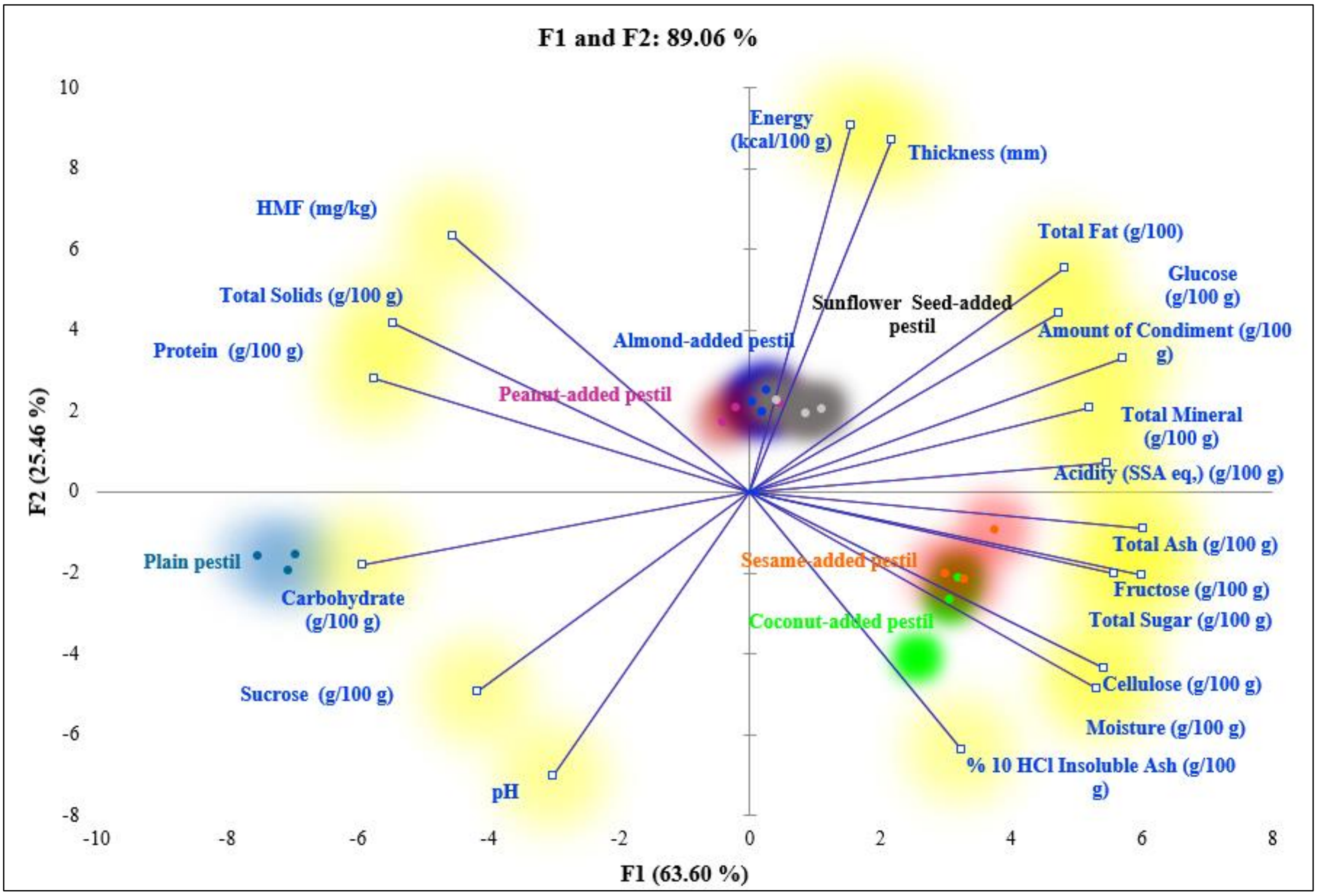

Figure 4. PCA analysis of physicochemical and chemical properties of the MLs. PC1 explains 63.60%, versus PC2 explains 25.46%

Fig. 4 illustrates positive correlations between variables situated close to each other and negative correlations between variables 180° apart. Furthermore, variables positioned 90° apart exhibit no significant correlation, suggesting their independence from each other [35]. The correlation matrix in **Table 4** supports this correlation pattern.

In Fig. 4, 16 principal components, excluding carbohydrates, sucrose, and pH, correlate positively with at least one of the two principal components (Table 4). Table 5 depicts the rotated loadings and communality for each element. Factor F1 (total mineral, total fat, cellulose, total sugar, glucose, fructose, total ash), both sesame-added pestil and coconut-added pestil exhibit high positive scores in F1, which indicates that these pestils are characterized by higher levels of total minerals, total fat, cellulose, total sugar, glucose, fructose, and total ash. The loadings table confirms this, as these components have strong positive loadings under F1, suggesting that F1 captures a group of nutrients that are more abundant in these pestils. In contrast, plain pestil has a highly negative score in F1, indicating that it contains lower levels of these components.

Factor F2 (amount of condiment, acidity, pH), almond-added pestil and peanut-added pestil show high positive scores in F2, which reflects their higher content of condiments and a specific pH range. This suggests that these pestils are richer in flavor-enhancing ingredients, influencing both their taste and acidity. The loadings table supports this, as amount of condiment and pH are positively correlated with F2. Therefore, pestils with higher F2 scores have more condiments and a more distinct pH level. On the other hand, sesame-added pestil and coconut-added pestil, with more negative scores in F2, likely contain fewer condiments compared to the other pestil types

Factor F3 (protein, sucrose, HMF), almond-added pestil has a notably negative score in F3, which is associated with lower levels of protein and sucrose. This suggests that almond-added pestil contains less of these nutrients compared to other pestils. In contrast, peanut-added pestil and sunflower seed-added pestil show moderate positive scores in F3, indicating that they have higher levels of protein and sucrose.

Factor F4 (moisture, pH), sunflower seed-added pestil stands out with the highest positive score in F4, suggesting it has higher moisture levels and a particular pH that distinguishes it from the other pestil types. Peanut-added pestil and sesame-added pestil show more moderate scores in F4, implying they have a more balanced combination of moisture content and pH.

Factor F5 (Acidity, % 10 HCl insol. ash), while factor F5 appears to have a less significant influence overall, it still reveals some interesting characteristics. For example, almond-added pestil has a relatively higher score in F5, suggesting it has a slightly different acidity or mineral content compared to the other pestils, which may influence its overall flavor and composition.

4. Conclusion

This study has revealed the feasibility of crafting MLs incorporated with alternative condiments. The ML samples generated three groups according to the physicochemical and chemical attributes. Strong correlations among the studied parameters were observed through multivariate statistical methods. The enriched MLs could serve as good sources of vital nutrients and energy. Significantly, the MLs developed also boast a notable mineral composition. The enriched MLs can contribute to the daily intake of required nutrients and energy as snacks or meals. The peanut-added ML may offer superiority over samples because of its lower sodium content. Sensory assessments have underscored the market potential of certain ML types if they are produced on an industrial scale. Consequently, this study has yielded products endowed with fresh taste and aromatic attributes. Based on our findings, the possibility of commercially producing ML types featuring flavors like sesame, coconut, and peanut is a viable prospect.

Based on the findings of this study, we recommend the commercial production and marketing of enriched ML products, especially those incorporating flavors like sesame, coconut, and peanut. These products not only show great promise in terms of their nutritional value and mineral composition, but they also have sensory attributes that are appealing to consumers. The development of MLs with added ingredients offers a significant potential to meet dietary needs, providing essential nutrients and energy in a convenient form, and making them suitable as snacks or meals. In conclusion, the sensory appeal, and enriched nutrient profile position these MLs as a promising product for commercial production. With the right marketing strategies focusing on their health benefits, convenience, and unique flavors, these products could successfully enter the market and meet growing consumer demand for nutritious, convenient snack and meal alternatives.

Funding

Supported by The GUBAP (Gümüşhane University Scientific Research Project Unit), Gümüşhane, Türkiye (Project No. GUBAP 16.A0110.02.01).

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of Interest: The authors have declared no conflict of interest.

References

[1] O. Sarma, M. Kundlia, H. Chutia, C.L. Mahanta, Processing of encapsulated flaxseed oil-rich banana-based (Dwarf cavendish) functional fruit leather, J Food Process Eng, 46, 2023, 14282.

[2] M. Barman, A.B. Das, L.S. Badwaik, Effect of xanthan gum, guar gum, and pectin on physicochemical, color, textural, sensory, and drying characteristics of kiwi fruit leather, J Food Process Preserv, 45, 2021, e15478.

[3] P. Sharma, M. Ramchiary, D. Samyor, A.B. Das, Study on the phytochemical properties of pineapple fruit leather processed by extrusion cooking, LWT, 72, 2016, 534–543.

[4] A. Das, B.N. Bora, H. Chutia, C.L. Mahanta, Processing of minerals and anthocyanins-rich mixed-fruit leather from banana (Musa acuminata) and sohiong (Prunus nepalensis), J Food Process Preserv, 45, 2021, e15718.

[5] L.M. Diamante, S. Li, Q. Xu, J. Busch, Effects of Apple Juice Concentrate, Blackcurrant Concentrate and Pectin Levels on Selected Qualities of Apple-Blackcurrant Fruit Leather, Foods, 2, 2013, 430–443.

[6] A. Maskan, S. Kaya, M. Maskan, Hot air and sun drying of grape leather (pestil), J Food Eng, 54, 2002, 81–88.

[7] R. da Silva Simão, J. Moraes, B. Carciofi, J. Laurindo, Recent Advances in the Production of Fruit Leathers, Food Eng Rev, 12, 2020, 68–82.

[8] H. Zhang, Z.F. Ma, X. Luo, X. Li, Effects of Mulberry Fruit (Morus alba L.) Consumption on Health Outcomes: A Mini-Review, Antioxidants, 7, 2018, 69.

[9] O. Yildiz, Physico-chemical and sensory properties of mulberry products: Gümüşhane pestil and köme, Turk J Agric For, 37, 2013, 762–771.

[10] F. Yuksel, B. Yavuz, C. Baltacı, Some physicochemical, color, bioactive and sensory properties of a pestil enriched with wheat, corn and potato flours: An optimization study based on simplex lattice mixture design, Int J Gastron Food Sci, 28, 2022, 100513.

[11] T. Mphaphuli, V.E. Manhivi, R. Slabbert, Y. Sultanbawa, D. Sivakumar, Enrichment of Mango Fruit Leathers with Natal Plum (Carissa macrocarpa) Improves Their Phytochemical Content and Antioxidant Properties, Foods, 9, 2020, 431.

[12] TSI 1125, Fruit and vegetable products- Determination of titratable acidity with a potentiometric reference method, Turkish Standard Institute, ISO 750, 2002.

[13] TSI 1728, Fruit and vegetable products-Determination of pH, Turkish Standard Institute, ISO 1842 (2001).

[14] S.Y. Quek, N.K. Chok, P. Swedlund, The physicochemical properties of spray-dried watermelon powders, Chem Eng Process, 46, 2007, 386–392.

[15] TSI 9131, Cezeriye (Turkish Special Carrot Sweet), Turkish Standard Institute, 1991.

[16] TSI 12677, Spread dried mulberry, Turkish Standard Institute, 2000.

[17] TSI 1562, Tea-determination of moisture content, Turkish Standard Institute, 1990.

[18] TSI 1620, Macaroni, Turkish Standard Institute, 2016.
[19] TSI 6180, Starches, native or modified, Determination of total fat content, Turkish Standard Institute, EN ISO 3947, 1997.
[20] TSI 6932, Agricultural Food Products-Determination of Crude Fibre Content-General Method, Turkish Standard Institute, 1989.
[21] TSI 1566, Tea- Determination of acid-insoluble ash, Turk Stand Institute, ISO 1577, 2001.
[22] TSI 2131, Spices and condiment- Determination of total ash, Turkish Standard Institute, ISO 928, 2001.
[23] NMKL 161, Determination by atomic absorption spectrophotometry after wet digestion in a microwave oven, NordVal International c/o Institute of Marine Research P.O. box 1870 Nordnes 5817 Bergen, Norway, 1998.
[24] C. Baltacı, Z. Akşit, Validation of HPLC Method for the Determination of 5-hydroxymethylfurfural in Pestil, Köme, Jam, Marmalade and Pekmez, Hittite J Sci Eng, 3, 2016, 91–97.
[25] O. Yildiz, G. Boyraci, Production and Some Quality Parameters of Sugar Beet Sweets (Pestil and Köme), Sugar Tech, 22, 2020, 842–852.
[26] M. Karaoğlu, Y. Bedir, H. Boz, Effect of whole grain flours on the overall quality characteristics of mulberry pestil, Qual Assur Saf Crops Foods, 12, 2020, 67–75.
[27] I. Tontul, A. Topuz, Effects of different drying methods on the physicochemical properties of pomegranate leather (pestil), LWT, 80, 2017, 294–303.
[28] S. Suna, A. Özkan-Karabacak, Investigation of drying kinetics and physicochemical properties of mulberry leather (pestil) dried with different methods, J Food Process Preserv, 43, 2019, e14051.
[29] H. Boz, M.M. Karaoğlu, G. Kaban, The effects of cooking time and sugar on total phenols, hydroxymethylfurfural and acrylamide content of mulberry leather (pestil), Qual Assur Saf Crops Foods, 8, 2015, 493–500.
[30] O. Cagindi, S. Otles, Comparison of some properties on the different types of pestil: a traditional product in Türkiye, Int J Food Sci Technol, 40, 2005, 897–901.
[31] H. Ulusal Bayram, Determine production methods and quality parameters of Gümüşhane pestil and Kome, Master Thesis, KTU Graduate School of Natural and Applied Sciences, Trabzon, Türkiye, 2018.
[32] M. Zappalà, B. Fallico, E. Arena, A. Verzera, Methods for the determination of HMF in honey: a comparison, Food Control, 16, 2005, 273–277.
[33] C. Baltacı, H. Ilyasoglu, A. Gundogdu, O. Ucuncu, Investigation of Hydroxymethylfurfural Formation in Herle, Int J Food Prop, 19, 2016, 2761–2768.
[34] N. Cayot, Sensory quality of traditional foods, Food Chem, 101, 2007, 154–162.
[35] S. Kopuzlu, A. Önenç, O. Bilgin, N. Esenbuga, Determination of meat quality through principal components analysis, J Anim Plant Sci, 21, 2011, 151–156.