



Original Research

Characterization of Traditional Stone-Milled Tahini (Sesame Paste) and its Oleogel-Structured Spreadable Alternative: Physicochemical, Functional, and Sensory Properties

Serife Cevik^{1,*}, Dilara Top², Gulcan Ozkan^{2,3}

¹Department of Food Process, Isparta University of Applied Sciences, Gelendost Vocational School, 32900 Isparta, Türkiye

²Food Engineering Department, Suleyman Demirel University, Faculty of Engineering and Natural Sciences, 32260 Isparta, Türkiye

³Innovative Technologies Application and Research Center, Suleyman Demirel University, 32260 Isparta, Türkiye

*Correspondence: serifecevik@isparta.edu.tr (Serife Cevik)

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Abstract

Background: To our knowledge, this study is among the first to investigate the development of spreadable tahini produced from traditionally stone-milled, dehulled sesame seeds using the oleogelation technique, in which mono- and diglycerides, stearin, and beeswax are compared as structuring agents. **Methods:** Initially, the basic quality characteristics of tahini were determined: 0.47% moisture, 61.5% fat, 23.31% protein, 4.40% total sugar, 0.59% invert sugar, 622.95 ppm γ tocopherol, 2.76 ppm α tocopherol, 0.210 mg total phenolic content (GAE/g), 3.67 mg/mL antioxidant activity (IC₅₀), 0.57% acidity as oleic acid, and 0.77 meq O₂/kg oil peroxide value. These results prove both the nutritional potential and oxidative stability of this spreadable alternative, which aligns with food safety standards. To optimize the spreadability and sensory properties of the prepared sesame-based product, different amounts of mono- and diglycerides (3%, 4%, and 5%), stearin (3%, 5%, and 6%), and beeswax (5%, 6%, and 8%) were used as gelling agents. **Results:** A 4% concentration of mono- and diglycerides appreciably enhanced the spreadability and consumer acceptability without sacrificing the distinctive chemical and sensory properties of the tahini. The optimum composition demonstrated high oxidative stability with a low peroxide value and a functional melting range of 33–40 °C, validating the potential of this product for commercial use as a spread. **Conclusion:** Oleogelation technology offers an environmentally friendly and clean-label alternative to the synthetic stabilizers conventionally used in tahini. The findings provide valuable information for plant-based functional food technology and are ready for industrial scaling within the scope of food technology, quality control, and product innovation.

Keywords: dehulled sesame; tahini; oleogelation; quality parameters; spreadability

1. Introduction

Sesame (*Sesamum indicum* L.) is an annual plant belonging to the Pedaliaceae family, grown for its oil- and protein-rich seeds [1,2]. Cultivated in tropical regions since ancient times, sesame is used extensively in Turkey as the basic raw material for producing sesame oil, tahini, and tahini halva, and is also consumed by sprinkling it on various bakery products [3–5]. Sesame seeds contain 50–60% oil and 18–28% protein and are also considered a healthy food option because they contain high amounts of carbohydrates, minerals, vitamins, and dietary fiber [2,6–10]. Sesame oil, which is found in high amounts in tahini, contains a lot of healthy unsaturated fatty acids and antioxidants such as sesamin, sesamol, and sesamol [11]. Sesame is used intensively in tahini production in our country, and according to the Turkish Food Codex, tahini is defined as a food product with high oil content and fluid consistency, obtained by roasting sesame seeds with or without dehulling and then homogenizing them by grinding [12]. The physicochemical characteristics of the tahini are based on the structural characteristics of the sesame used and various process usage in the process steps of the dehulling

(optional), roasting, and grinding steps [13–18]. To successfully transfer the high nutritional potential to the tahini product, several technological processes are required, such as dehulling, roasting, and crushing. These stages directly impact the nutritional level, flavor profile, and sensory characteristics of the final product. After the removal of the hulls, the moisture level of the sesame seed decreases to 3–5%, and the roasting phase is applied, generally in the pans of the rotary roasting device or the electric oven between 100–150 °C [14]. The roasting phase plays a direct and important role in the formation of the specific smell and unique flavor profile, and thus the quality, of the tahini product [16,17]. Studies show that the oil in tahini usually contains 80–85% unsaturated fatty acid, and the heat applied to the seeds does not significantly alter the fatty acid composition. Tahini is a product rich in carbohydrates and dietary fiber, as well as high in fat and protein [19]. Sesame oil having better oxidative stability than other oils include the natural antioxidant factors sesamol, sesamin, and trace sesamol [20]. Tahini is widely used in various product groups in Turkey, from baked goods to confectionery, salads to appetizers, and pastries, tahini milk, and



is also considered an important ingredient in halva production [4,13,21–23]. Moreover, its direct consumption along with molasses/honey for breakfast is also very common [3,13,22,23]. Thanks to these traditional forms of use and local production techniques, some tahini varieties have been protected by the “Geographical Indication” registration [13]. In recent years, the development of structurally and sensorially enhanced, highly stable, and trans fat-free spreadable products has become a priority due to growing consumer interest in functional foods. Research has increased in this context on the development of emulsion-oleogel systems that are semi-solid at room temperature, completely oil-based, spreadable, and exhibit a variety of rheological properties. Organogelation, a prominent technique in this field, is based on the physical stabilization of liquid oils by coating them in a three-dimensional network structure [24]. Organogelators allow precise control of basic rheological properties, including texture, elasticity, and aeration, in food products by trapping the liquid component within the gel matrix [25]. Previous studies focused on preventing phase separation, commonly observed in sesame paste and sesame-based products, and investigated various methods, including an addition of molasses or honey [26,27], as well as the utilization of different stabilizers, dietary fibers, natural waxes, and plant extracts [28–30]. Mono- and diglycerides, extensively utilized in oil-based systems, provide structural stability as well as decrease phase separation due to their emulsifying properties and ability to form crystal structures [31,32]. In contrast, natural lipophilic gelators such as stearin and beeswax can physically entrap the liquid oil phase within a crystalline network, thereby enhancing the oxidative stability and spreadability of oleogel systems [33,34]. Nevertheless, a comprehensive study on the production of solid-phase structured, spreadable breakfast tahini using tahini structured by hulled and singly roasted sesame seeds by the traditional stone milling process, applying the oleogelation technique utilizing different percentages of gelling agents such as mono- and diglycerides (MAG and DAG), stearin, and beeswax, has not yet been published in the literature.

The objective of this study is to address the identified literature gap by developing a functional tahini product in a spreadable form that includes various food-grade gelators. The tahini was obtained through the traditional stone milling technique, and the rheological, thermal, physico-chemical, and sensory properties of the product were systematically assessed.

2. Material and Methods

2.1 Material

The sesame seeds (*Sesamum indicum* L.) to produce tahini were purchased from Emir Agro Gıda San. Ltd. Şti A.Ş. (Eskisehir, Türkiye) Mono- and diglycerides (MAG and DAG) and stearin were obtained from Kalealtı Çöğ.Thl.

San. Ltd.Şti (İstanbul, Türkiye), and Kahlwax brand refined beeswax was obtained from Ejder Kimya A.Ş. (İstanbul, Türkiye).

Beeswax, a natural wax secreted by *Apis mellifera* L., is widely utilized in the food industry due to its multifunctional properties. It is approved as food additive E901 under international regulations, including the U.S. FDA framework (21 CFR 184.1973), for use as a stabilizer, texturizer in gum-based systems, carrier for flavors and colors, and as a clouding, coating, and release agent. Its composition typically includes 70–71% esters of long-chain fatty acids and alcohols, 1–1.5% free alcohols, 9–11% free acids, and 12–15% hydrocarbons [35–37]. These hydrophobic components form an ordered crystalline lattice capable of immobilizing oil droplets, thereby reinforcing the oleogel network in tahini. This structural arrangement enhances oil-binding capacity, reduces phase separation, and influences rheological behavior by imparting a semi-solid texture. In our formulation, beeswax primarily interacts with the lipid fraction of tahini (approximately 50–60% of its composition) through hydrophobic and van der Waals forces, leading to a three-dimensional network that entraps the continuous oil phase. This mechanism differs from that of mono- and diglycerides and stearin, and its effects on textural and stability parameters have been comparatively assessed in our results. Mono- and diglycerides function as emulsifiers that stabilize texture and prevent oil–water separation. They are commonly applied in fat-based products such as margarine, spreads, shortenings, and cake mix, and in dairy emulsions like ice cream and recombined milk (often combined with hydrocolloids). Classified as GRAS (Generally Recognized as Safe) in the U.S. and permitted under EU legislation, they can be used in food products, quantum satis, with no established acceptable daily intake [38]. Stearin, the solid fraction rich in lauric acid obtained from palm kernel oil, is extensively used in fat-based applications such as margarine, cocoa butter substitutes, ice cream, and non-dairy whipping creams [39]. Its crystalline structure provides firmness and contributes to the overall mouthfeel and spreadability of the oleogel system in tahini.

2.2 Production of Single Roasted Tahini From Unhulled Sesame Seeds Using Traditional Methods

Tahini production was carried out in Özgıda Toposmanoğlu Company using a traditional stone mill according to the flow chart given below (Fig. 1). During the production process, sesame seeds were first sieved to remove foreign materials. Then, for the hulling and separation processes, the seeds were kept in water containing 12–14% salt for a certain period to soften the hulls. After this process, the sesame seeds were washed 5–6 times to remove the salt. The hulls were separated by mechanically beating and crushing them using a rotating trommel dehuller. The surface moisture of the dehulled sesame seeds was removed by centrifugation. The seeds were then roasted at 150 °C

for 2 hours. Following the roasting process, the seeds were allowed to cool down by resting for 12 hours. After resting, the seeds were sieved again and ground in a traditional stone mill to obtain tahini. Tahini was filled into a 1000 mL plastic bottle and was stored in a cool and dry place at room temperature until the analyses were performed.

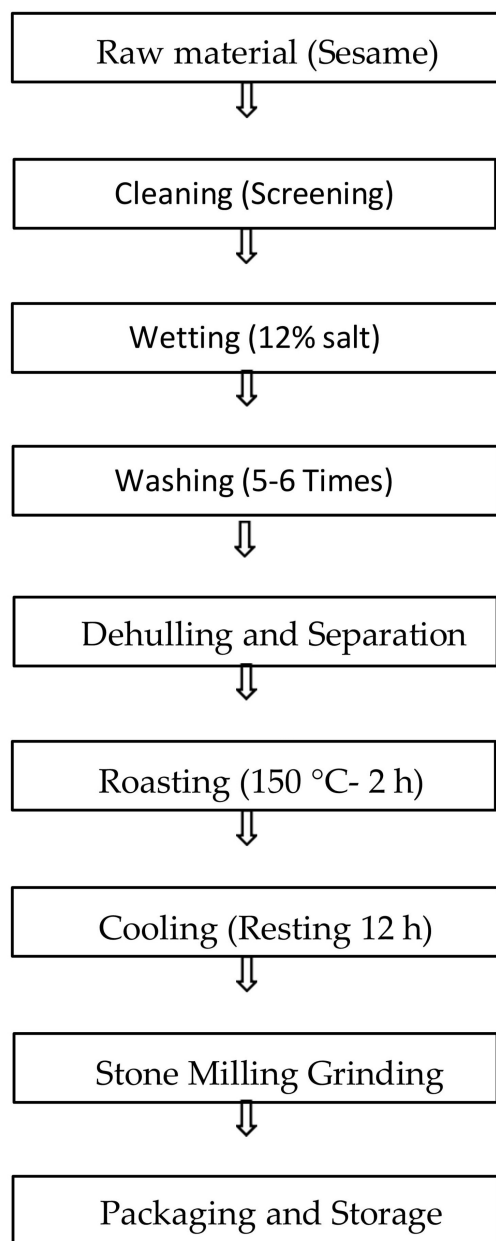


Fig. 1. Sequential flowchart of traditional tahini production from dehulled sesame seeds using the stone milling method.

2.3 Spreadable Tahini Preparation

For beeswax, mono- and diglycerides, and stearin, the starting concentrations were determined according to their distinct oil-binding capacities, melting behaviors, and

structuring efficiencies, as reported in earlier studies [24, 40]. Due to the significant differences in gelling power and crystalline network formation between these agents, identical concentration values would not yield comparable textural or stability outcomes. Instead, each gelling agent was tested within a concentration range sufficient to identify its optimal technological performance in spreadable tahini.

Our approach is consistent with previous oleogel research, where concentration ranges are tailored to the physical–chemical characteristics of each structurant to achieve a standardized target texture or spreadability rather than identical dosage levels [24]. For example, beeswax typically forms a stable gel at lower concentrations (3–5%), while stearin requires higher levels to achieve similar firmness due to its crystalline morphology and melting profile [24,40]. The final concentrations reported in this study thus represent optimized values for each gelling agent, determined through iterative trials to meet specific sensory and rheological benchmarks. This method ensures a fair functional comparison of different gelators within the context of tahini formulation, aligning with best practices in oleogelation research.

In this work, spreadable formulations were developed using tahini as the continuous in rich phase. The tahini mixture was thickened with various percentages of beeswax (5%, 6%, and 8%), stearin (3%, 5%, and 6%), and mono- and diglycerides (MAG and DAG) (3%, 4%, and 5%). Using a magnetic stirrer, each mixture was heated to approximately 90 °C and stirred until a transparent and visually uniform dispersion was achieved. To ensure that the gel agents dissolved completely in the tahini, the processing temperature of approximately 90 °C was chosen based on their melting temperatures. Then, 50 mL samples of the oleogel mixtures were put into clean vials and cooled at a controlled room temperature for 24 hours to help them gel and stabilize before testing their analyses [30,40].

2.4 Determination of Oil Content

The oil contents of the tahini were determined through the Soxhlet extraction according to the American Oil Chemists’ Society (AOCS) method [41]. For all determinations, 5–10 g of homogenized sample of tahini were accurately weighed and extraction solvent used in the present study is hexane (Sigma-Aldrich, Darmstadt, Germany) (150 mL), and the process of extraction continued for 6 hours under static conditions of reflux. Following the process of extraction, the solvent is recovered through the process of evaporation, and the weight of oil left is recorded. The oil yield was calculated gravimetrically based on the initial sample weight using Eqn. 1:

$$\text{Oil Content (\%)} = \frac{\text{Weight of extracted oil (WW)}}{\text{Weight of tahini sample (WW)}} \times 100 \quad (1)$$

All results were expressed as a percentage of oil on a wet basis.

2.5 Determination of Free Fatty Acidity

The free fatty acidity (FFA) of tahini samples was determined according to the official The American Oil Chemists' Society (AOCS) method [42], and the results were expressed as a percentage of oleic acid. For the analysis, an accurately weighed portion of the tahini sample was dissolved in a neutralized solvent mixture, followed by titration with 0.1 N potassium hydroxide (KOH) (Merck, Darmstadt, Germany). solution using phenolphthalein (Sigma-Aldrich, Darmstadt, Germany) as an indicator. The volume of KOH consumed during titration was recorded. FFA was calculated according to Eqn. 2:

$$\text{Free Fatty Acidity (Oleic Acid \%)} = \frac{v}{m} \times 2.8 \quad (2)$$

Where:

V: volume (mL) of 0.1 N KOH used for titration; m: mass (g) of the tahini sample.

2.6 Determination of Peroxide Value

The peroxide value (PV) of tahini oil samples was determined according to the AOCS Official Method [43]. The PV is expressed as the amount of peroxide oxygen (in milliequivalents) per kilogram of oil sample. The calculation is based on the following formula:

$$\text{Peroxide Value} = \frac{(v - V_{\text{blank}})}{m} \times 2.8 \quad (3)$$

Where:

V: Volume (mL) of sodium thiosulfate solution used for sample titration;

V blank: Volume (mL) of sodium thiosulfate used for blank titration;

m: Weight (g) of tahini sample.

This equation is valid when using 0.002 N sodium thiosulfate solution.

2.7 Determination of Moisture and Total Dry Matter

The moisture content of the tahini samples was determined by the gravimetric method. Approximately a 15 g tahini sample was weighed with 0.01 g sensitivity into pre-dried and pre-weighed petri dishes. They were placed in an oven set at 105 °C and held for 24 hours. After drying, the samples were transferred to a desiccator to cool to room temperature. The final weight was recorded once a constant weight was achieved. The moisture content was calculated using the following formula:

$$\text{Moisture (\%)} = \frac{(Wt - Ws) \times 100}{m} \quad (4)$$

$$\text{Total Dry Matter (\%)} = 100 - \text{Moisture} \quad (5)$$

Where:

Wt: Weight of petri dish and wet sample (g);

Ws: Weight of petri dish and dried sample at constant weight (g);

m: Mass (g).

2.8 Extraction and Quantification of Tocopherols From Tahini Using HPLC

Tocopherol content in the tahini samples was determined using a modified version of the AOCS Official Method Ce 8–89 [44]. The analysis was performed on oil previously extracted from tahini samples using the Soxhlet method, ensuring high lipid recovery and representative tocopherol distribution. For analysis, 250 µL of extracted oil was dissolved in a 1 mL mixture of mobile phase solvent composed of n-heptane and tetrahydrofuran (THF) at a volume ratio of 95:5 (v/v). The mixture was vortexed until complete dissolution and filtered through a 0.45 µm Polytetrafluoroethylene (PTFE) syringe filter. A 20 µL aliquot of the filtered solution was then injected into the high-pressure liquid chromatography system. A fluorescence detector (RF –10AXL, Ex 295nm- Em 330 nm) was used with wavelengths set at 295 nm for excitation and 330 nm for emission. The data was integrated and analyzed using Shimadzu Lab Solutions Chromatography Laboratory Automated Software system (LCsolution Version 1.11SP1, Shimadzu, Kyoto, Japan). Quantitative determination of individual tocopherol isomers (α-, β-, γ-, and δ-tocopherol) was performed using certified reference standards (Merck, Darmstadt, Germany). All analyses were conducted in triplicate to ensure reproducibility and accuracy.

2.9 Total Sugar and Invert Sugar Determination

Total and invert sugar contents of the samples were determined using the classical Luff- Schoolt titrimetric method [45,46]. In this procedure, the sample was initially clarified using Carrez I (potassium ferrocyanide) and II (zinc sulfate) solutions to remove interfering proteins and colloidal substances. Following clarification, the solution was appropriately diluted to fall within the analytical range. For the determination of reducing sugars (invert sugar), aliquots of the sample were boiled with Luff reagent, which contains copper sulfate in an alkaline medium. While heating, reducing sugars changed Cu²⁺ ions into Cu⁺, and the extra copper was then removed. After cooling, potassium iodide (Isolab, Eschau, Germany) and sulfuric acid (Sigma-Aldrich, Darmstadt, Germany) were added to change any leftover copper into iodine, which was then measured using a standardized sodium thiosulfate solution with a 1% starch indicator (Merck, Darmstadt, Germany). The total sugar content was found by doing the same steps again after breaking down the non-reducing sugars (mostly sucrose), and the final amount was calculated by adding the volumes

of thiosulfate used before and after this breakdown. The results were expressed as percentage sugar content in the sample.

2.10 Determination of Total Phenolic Content

The total phenolic content (TPC) of tahini samples was determined using the Folin–Ciocalteu colorimetric assay [47]. Briefly, appropriately diluted samples were reacted with Folin–Ciocalteu reagent and sodium carbonate under alkaline conditions. After incubation, the absorbance was measured at 765 nm using a ultraviolet–visible spectrophotometer. Results were expressed as milligrams of gallic acid equivalents per gram of tahini (mg GAE/g).

2.11 Determination of Antioxidant Activity by DPPH Radical Scavenging Assay

The antioxidant capacity of the samples was assessed by the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging method [48]. A methanolic DPPH solution was mixed with tahini extract, and the decrease in absorbance was recorded at 517 nm after incubation in the dark. The antiradical activity was quantified as IC_{50} , representing the concentration required to inhibit 50% of the DPPH radicals, and was expressed in mg/mL.

2.12 Determination of Textural Properties of Spreadable Tahini Samples

To evaluate the textural characteristics of spreadable tahini formulations, all samples were stored at 4 °C for 24 hours after preparation to allow structural stabilization. Subsequently, hardness and stickiness parameters were analyzed using a texture analyzer (TA. XT Plus, Stable Micro Systems, Surrey, UK) equipped with a stainless-steel spherical probe (P/0.75S). After calibrating the weight and height of the texture analyzer, the test conditions were adjusted. The test was conducted in the following conditions: the speed of the probe in the pre-test equaled 1 mm/s, and after the test to 2 mm/s. During analysis, the instrument's probe could penetrate the sample to 15 mm in depth to the trigger force of 0.5 g. The method stipulates determining the characteristic texture parameters without disruption to the structural integrity of the samples, like previously pointed out by Moskowitz and Jacobs (2017) [49]. The value of the maximum force, which is attained in the process of compression, was established as “hardness” and revealed the level of the sample resistance to external force. The negative force of probe retraction was taken into consideration in the analysis and revealed information on the adhesion of the sample to the surface [49].

2.13 Sensory Analysis

Sensory evaluation of the spreadable version of the tahini was conducted through the hedonic testing method for the consumer's preference. A 5-point hedonic scale was used, i.e., 1 = extremely poor to 5 = excellent, and

12 trained panelists scored the samples for various sensory attributes. The sensory evaluation panel consisted of (young and middle-aged individuals, men and women) faculty, graduate students (food engineering; undergraduate graduates, MSc/PhD students), and academic staff from Süleyman Demirel University. The panelists received brief training on the necessary steps between tastings, including drinking water, chewing, swallowing, and the time required for these procedures. Thus, the samples were scored for structure (stickiness, hardness, spreadability, and waxy texture), and taste (desirable pleasant taste, burnt flavor, unpleasant taste). The sensory analysis data obtained were used in evaluations to determine which gelling agent is more suitable in terms of sensory quality in the production of spreadable tahini. As a result of the overall taste scoring considering all sensory parameters, the sample with the highest score was determined as the best-performing formulation [50].

2.14 Differential Scanning Calorimeter Analysis

Differential Scanning Calorimeter (DSC) analyses of spreadable tahini samples were carried out at Burdur Mehmet Akif Ersoy University Scientific and Technology Application and Research Center with AOCS Official Method Cj 1-94. The working conditions used in the analysis are given below.

Brand: PerkinElmer Model: DSC 4000 Sample Amount: 3–10 mg.

Working Principle: It was heated from 25 °C to 100 °C in a nitrogen environment in increments of 10 degrees per minute and kept for 10 minutes, then cooled from 100 °C to –50 °C and kept for 30 minutes and heated from –50 °C to 100 °C [40].

2.15 Statical Analysis

The results of the research were tested for statistical significance using one-way analysis of variance (ANOVA). The data were analyzed by one-way ANOVA followed by Tukey's multiple comparison test to determine significant differences at the $p < 0.05$ level. Statistical analysis was performed to determine whether three different oleogelators (mono- and diglyceride, stearin, and beeswax) had a significant effect on the hardness and adhesive properties of tahini samples at different concentration levels. All statistical analyses were conducted using IBM SPSS Statistics software, version 22.0 (IBM Corp., Armonk, NY, USA).

3. Results and Discussion

The results of compositional analysis of tahini from unhulled sesame by traditional stone mill are given in Table 1.

The data were compared with the Turkish Food Codex Communiqué on Tahini (Communiqué No: 2015/27) [12], it was observed that the tahini sample complies with all legal limits. According to the Communiqué, the moisture

Table 1. Compositional analysis of tahini obtained from dehulled and singly roasted sesame seeds using traditional stone milling.

Component	Mean
Oil (%)	61.50 ± 0.70
Protein (%)	23.31 ± 0.50
Acidity (%Oleic acid)	0.57 ± 0.02
Peroxide (meq O ₂ /kg oil)	0.77 ± 0.04
Moisture (%)	0.47 ± 0.04
Total Phenolic Content (mg GAE/g tahini)	0.21 ± 0.002
Antioxidant Activity (IC ₅₀ (mg/mL))	3.67 ± 0.002
Total Sugar (%)	4.40 ± 0.13
Invert Sugar (%)	0.59 ± 0.05
α tocopherol (ppm)	2.76 ± 0.01
β tocopherol (ppm)	nd
γ tocopherol (ppm)	622.95 ± 11.85
δ tocopherol (ppm)	nd

nd, not detected; ±, standard deviation.

content should not exceed 1.5%, protein content should be at least 20%, ash content should be a maximum of 3.2%, and acidity (expressed as oleic acid) should not exceed 2.4%. In this context, the measured moisture, protein, and acidity values of the tahini sample were found to be fully consistent with Codex specifications. Particularly, the low moisture and acidity values are advantageous for the microbial stability of tahini, contributing positively to its shelf life. Additionally, the low peroxide value supports the oxidative stability of the oil phase, maintaining the freshness of the product. Although total phenolic content and antioxidant activity values, which are not directly regulated by the Codex but are important for functional foods, show that tahini is not only a traditional product but also an ingredient with health-promoting potential. This provides an important advantage in terms of evaluating tahini-based products in the functional food market.

In addition, the low total and invert sugar content of tahini and spreadable tahini suggest that the product can be adapted for special diets that require sugar control. The compositional findings of the present study were consistent with results already established in the literature. Studies in the literature related to the composition of the product reported it to contain 43.25–65% fat, 20.30–27% protein, 4–9% carbohydrate, 9.3% dietary fiber, and 1–1.5% moisture. Additionally, the product was reported to be a good source of various minerals and vitamins such as calcium, magnesium, phosphorus, potassium, and vitamin A and B complex [6,51–53]. Özcan *et al.* (2023) [10] reported the total phenolic material of raw sesame to be 35.05 mg GAE/100 g. It was lower after the production of tahini, at 12.45 mg GAE/100 g, indicating a reduction of these phytochemical compounds during the process. The information gained in the present study clearly demonstrates that the product has not only great nutritional value but also the potential to be

used as a functional food ingredient due to its antioxidant activity. The studies conducted provided a strong foundation for developing spreadable tahini formulations based on scientific information, facilitating a systematic study of the structured product's quality, stability, and functional characteristics. The textural properties of the spreadable tahini were subsequently measured in terms of hardness (g force) and stickiness value (g force) and these results are given in Table 2 (Ref. [54]).

The hardness and stickiness values of spreadable tahini developed by adding mono-di glycerides to tahini ranged between 101.60 and 373.34 g force and –22.27 and –102.14 g force respectively. In the formulations containing stearin, hardness values of ranged from 133.87 to 811.48 g force, whereas the stickiness values varied between –97.88 and –51.16 g force. In spreadable tahini preparations of beeswax, the value of hardness was 148.2–279.4 g force, and the value of stickiness ranged between –87 and –49.56. When evaluated from a statistical perspective, the results show that the concentration of mono- and diglycerides had a statistically significant effect on hardness. As the concentration increased, stickiness also increased significantly. A significant rise in hardness values was observed, and this difference was statistically significant ($p < 0.05$). In particular, 6% stearin showed a striking increase in hardness. For adhesiveness, the differences were less pronounced, but still statistically significant. As beeswax concentration increased, a steady increase in hardness was observed, and this difference was statistically significant ($p < 0.05$). Adhesiveness values also showed significant differences ($p < 0.05$). We confirmed that the spreadable tahini composition containing 4% mono- and diglycerides had the best spreadability characteristics, hardness, and stickiness. These textural results show that the composition can be used as a product prototype optimized for both consumer acceptability and sensory performance. Overall, the type and the level of gelators employed had pronounced effects on the structural and textural characteristics of the tahini spread. The experiment revealed that oleogelation is an efficient approach to modifying the textural characteristics of tahini-based products to increase consumer acceptability. In line with these results, Ogutcu *et al.* (2018) [30] reported that adding natural gelling agents such as sunflower wax and beeswax to tahini increased the product's viscosity, causing it to exhibit pseudoplastic flow behavior. Additionally, the natural gelators improved the rheological characteristics by creating a homogeneously structured matrix compatible with the oil phase, greatly contributing to spreadability.

As observed in Fig. 2, the spreadable sample of tahini made using mono- and diglycerides presented the best scores in almost all the sensory characteristics considered, which indicate better overall acceptability. Specifically, the sample presented favorable characteristics for stickiness, hardness, spreadability, waxy texture, and good flavor, which would reflect an enjoyed well-balanced texture

Table 2. Textural parameters (hardness and stickiness value, g force) of spreadable tahini formulated with different gelling agent concentrations (adopted from previously published study by Top *et al.*, [54]).

Samples	Concentration (%)	Hardness (g, force)	Stickiness (g, force)
Mono and diglyceride	3	101.60 ± 4.46c*	-22.27 ± 2.72c
Mono and diglyceride	4	209.38 ± 4.02b	-69.76 ± 2.20b
Mono and diglyceride	5	373.34 ± 4.00a	-102.14 ± 3.63a
Stearin	3	133.87 ± 2.90c	-51.16 ± 4.68b
Stearin	5	250.56 ± 9.40b	-87.50 ± 2.99ab
Stearin	6	811.48 ± 6.08a	-97.88 ± 1.91a
Beeswax	5	148.20 ± 0.78c	-49.56 ± 3.40c
Beeswax	6	189.81 ± 4.88b	-61.50 ± 3.53b
Beeswax	8	279.40 ± 0.26a	-87.00 ± 4.93a

±: standard deviation, *Significant at 0.05% level, different letters indicate the statistical difference within rows.

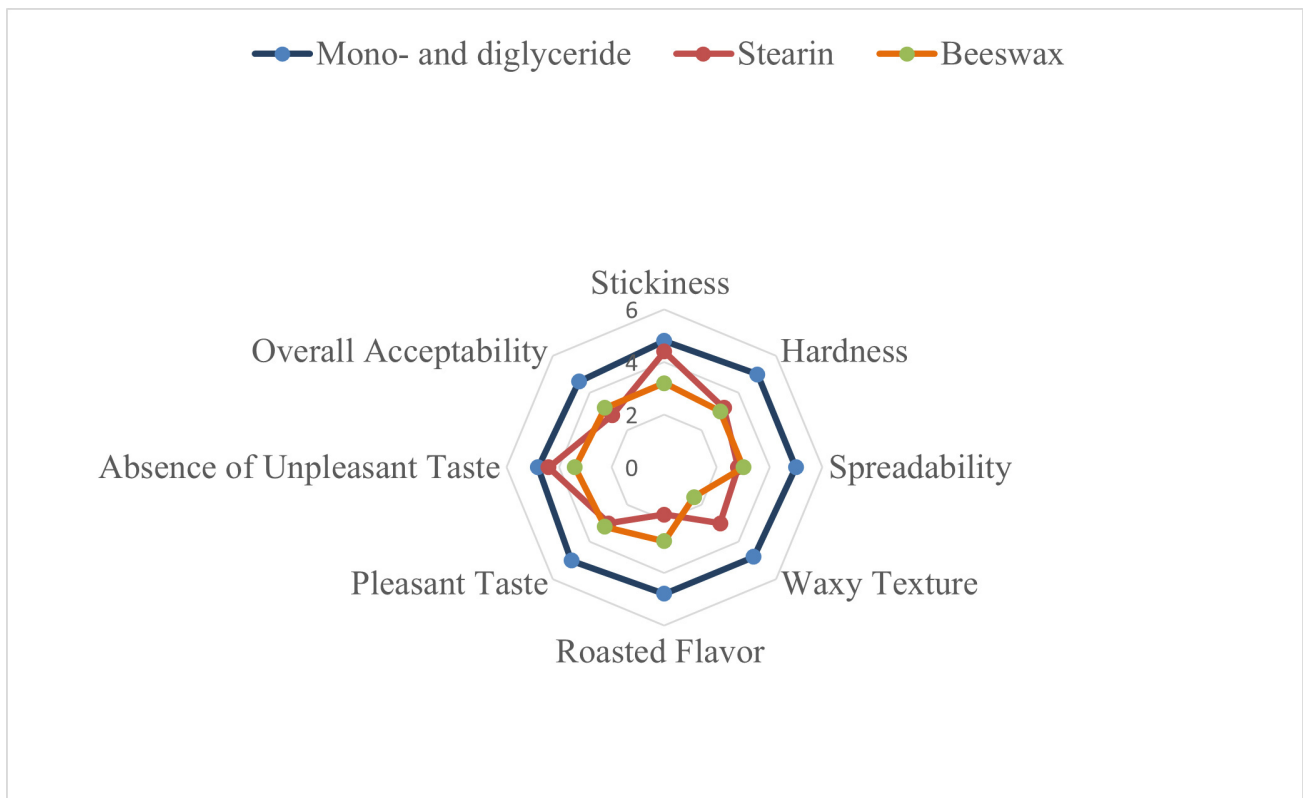


Fig. 2. Sensory attributes of spreadable tahini products.

and flavor pattern. In line with these arguments, the sample made using beeswax had low spreadability and stickiness values, which would have otherwise compromised its overall acceptability. The sample made with stearin had intermediate values, exceeding the beeswax sample in overall approval but not matching the mono- and diglyceride sample, especially in terms of spreadability and burnt flavor. In general, these results suggest that using mono- and diglycerides offers a significant advantage in producing a functionally spreadable tahini product with good sensory characteristics, whereas other gelling agents could compromise the texture and/or flavor. Samples containing mono- and

diglycerides represented “Group A”, achieving the highest statistically significant scores across all sensory parameters. Beeswax and stearin samples generally had lower means and were placed in different letter groups, making them statistically significantly different from mono- and diglycerides. This demonstrates that the use of mono- and diglycerides had a significant and positive impact on sensory quality ($p < 0.05$).

The 4% mono- and diglyceride-rich composition of tahini had the highest scores in all the textural properties (4.8–5 range) when scored for stickiness, hardness, spreadability, waxy sensation, and burnt flavor. This achievement

Table 3. Fatty acid composition of tahini and spreadable tahini.

Fatty Acid (%)	Tahini Mean	Spreadable Tahini Mean
Myristic Acid (C14:0)	-	0.03 ± 0.00
Palmitic Acid (C16:0)	9.41 ± 0.01	10.94 ± 0.01
Palmitoleic Acid (C16:1)	0.12 ± 0.00	0.12 ± 0.00
Stearic Acid (C18:0)	6.17 ± 0.00	7.09 ± 0.01
Oleic Acid (C18:1n9)	40.03 ± 0.01	38.82 ± 0.01
Linoleic Acid (C18:2n6)	42.80 ± 0.01	41.57 ± 0.01
Arachidic Acid (C20:0)	0.67 ± 0.00	0.66 ± 0.00
γ -Linolenic (18:3n3)	0.33 ± 0.00	0.33 ± 0.01
cis-11-Eicosenoic Acid (C20:1)	0.19 ± 0.00	0.18 ± 0.00
Behenic Acid (C22:0)	0.14 ± 0.00	0.14 ± 0.00
Lignoceric Acid (C24:0)	0.09 ± 0.00	0.09 ± 0.00
Nervonic Acid (C24:1n9)	0.04 ± 0.00	0.04 ± 0.00

±, standard deviation.

is attributed to the emulsifying and structure-regulating effects of mono- and diglycerides. In addition, the gelators provide a homogeneous distribution of fat and solid phases within the tahini matrix, improving both the spreadability and structural integrity of the product [55]. The panelists evaluated the resulting formulation positively due to its semi-fluid consistency, appropriate adhesive properties, and high sensory acceptance. On the other hand, the panelists evaluated formulations containing stearin with scores of medium hardness (3.2) and low spreadability (2.8). The high melting point of stearin (~55–60 °C) causes the product to be more solid at room temperature, negatively affecting spreadability [56]. Therefore, the spreadable tahini that includes stearin results in poorer spreadability and a texture that consumers may not like as much. Natural refined beeswax showed overall poor structural performance. In particular, the scores attributed to beeswax were waxy texture (1.6) and burnt flavor (2.8). Indicating that the crystalline structure and hardness of this additive negatively affect the spreadability of the product [33]. In sensory evaluations, spreadable tahini prepared using mono- and diglycerides received the highest scores for pleasant taste (5.0) and overall acceptance (4.6). It provided a balanced flavor profile while preserving the natural properties of tahini, improving the flavor of the product. The sensory questionnaire also positively scored the formula for the mouthfeel and the light, smooth tasting flavor. On the other hand, there were unfavorable sensory ratings of 4.4 for the test sample containing stearin due to its undesirable flavor. It is suspected that this undesirable effect is due to the soapy- or waxy-tasting perception of the stearin in the product [56].

The sample to which stearin was added scored 4.4 on the undesirable taste parameter, and the dislike was generated by stearin creating soapy/waxy side flavors; Thus, the sensory quality of the product is seen to be impaired [56]. Beeswax-based products scored low for agreeable

Table 4. Protein content (%) and fatty acid composition (%) of tahini and spreadable tahini samples.

Component	Tahini mean	Spreadable Tahini mean
Saturated Fatty acid (%)	16.49 ± 0.35	18.95 ± 0.42
Unsaturated Fatty acid (%)	83.51 ± 0.35	81.05 ± 0.42
Protein rate (%)	23.31 ± 0.51	20.56 ± 0.48

±, standard deviation.

taste (3.2 and 2.4) and overall acceptability (3.2 and 2.2). This is seen to reflect the common waxy mouthfeel of such vegetable-based additives, which are often off-putting to panelists [33]. Overall evaluation and consumer acceptance: When the radar graph and sensory analysis data were evaluated together, the formulation with mono- and diglyceride additives obtained the highest overall scores in both structural and sensory parameters. These results indicate that the product has a balanced functional and sensory profile, meeting consumer expectations. Although stearin addition enhanced certain structural properties, it adversely impacted the sensory characteristics of the product. Conversely, samples containing beeswax showed unsatisfactory structural and sensory performance, indicating limited applicability for industrial production and consumer acceptance. When the spreadability test, mechanical texture analysis, and sensory evaluation findings were evaluated together, the tahini formulation containing 4% mono- and diglycerides demonstrated a superior performance than all other additives. These values suggest that the product maintains a semi-fluid and spreadable consistency while simultaneously exhibiting adequate adhesion to the substrate, thereby ensuring uniform spreadability. The negative stickiness value also supports that the product leaves a pleasant mouthfeel without much residue. In addition to these parameters, the fact that the panelists rated this formulation as the most favorable in terms of spreadability, mouthfeel, and taste proves that mono- and diglycerides have not only textural but also sensory quality-enhancing effects. The emulsifying and structure-stabilizing properties of this gelling agent ensure a homogeneous distribution of fat and solid phases within the tahini matrix, positively affecting shelf life and consumer experience. In conclusion, mono- and diglyceride additives stand out as the most suitable gelling agent for the development of functional, spreadable, and consumer-friendly tahini products. The sample containing 4% mono- and diglycerides, identified as the optimal formulation in the process of optimizing spreadable tahini formulations, was further evaluated through advanced analytical techniques. In this context, the fatty acid composition of both the traditional tahini and the selected spreadable tahini sample was comparatively analyzed, and the results are presented in Table 3.

As shown in Table 3, both samples were found to be rich in unsaturated fatty acids, indicating a favorable lipid profile in terms of cardiovascular health. The observed in-

Table 5. DSC results of spreadable tahini samples.

Samples	Crystallization (Tc)			Melting (Tm)		
	a Onsetc (°C)	Peak (Tc. °C)	Hc (J/g)	Onsetc (°C)	Peak (Tm. °C)	Hm (J/g)
ST	21.56 ± 0.54	16.94 ± 0.47	-2.297 ± 0.29	33.20 ± 0.01	40.04 ± 1.43	10.77 ± 2.36

±, standard deviation; ST, spreadable tahini; DSC, differential scanning calorimeter.

crease in saturated fatty acids such as palmitic acid (C16:0) and stearic acid (C18:0) in the tahini sample further supports these findings. Oleic acid (C18:1n9) and linoleic acid (C18:2n6) were identified as the predominant unsaturated fatty acids in tahini and were present in high concentrations (approximately 40%) in both the traditional and spreadable tahini samples. The anti-inflammatory properties and positive modulatory effects of these fatty acids on lipid metabolism and cardiovascular risk factors have been widely reported in scientific literature. The fatty acid profile observed in the spreadable tahini formulation suggests that it preserves functional characteristics analogous to those of the native tahini. Özcan and Akgül (1994) [52] evaluated the physical-chemical analysis and fatty acid composition of tahini and reported that it contained 9.55–10.32% palmitic, 37.42–45.04% oleic, and 43.25–52.34% linoleic acids as nutritionally important fatty acids. Although minor modifications were detected in the tahini matrix upon incorporation of mono- and diglycerides, these alterations remain within tolerable limits concerning food quality parameters. When evaluated in conjunction with the observed enhancements in physical attributes such as structural stability and spreadability, these changes confer a functional advantage. The enhancement of the functional properties of the spreadable tahini formulation through the incorporation of gelling agents, without inducing significant alterations in its fatty acid composition, constitutes a substantial advancement from both scientific and industrial perspectives. In conclusion, the fatty acid composition of the selected sample is both similar to that of traditional tahini and provides the nutritional and structural properties required for the formulation of a functional spreadable product. This proves both the health safety and the preservability of the functional components of the spreadable tahini sample and shows that the developed product is promising in terms of industrial-scale applicability. In this context, total saturated and unsaturated fatty acid ratios and protein contents of tahini and spreadable tahini samples were analyzed comparatively, and the results are presented in Table 4.

In terms of protein content, the traditional tahini and spreadable tahini samples exhibited a protein level of over 20%, thus tahini samples meet the minimum protein requirement of 20% stipulated by the Turkish Food Codex Tahini Regulation, thereby demonstrating compliance with nutritional quality standards. In light of this data, the developed spreadable tahini product can be considered functional

spreadable food rich in protein and unsaturated fatty acids. The slight increase observed in saturated fatty acid content may contribute positively to the product's shelf stability and textural resilience, although it remains a parameter that warrants careful monitoring from a nutritional perspective.

These findings once again emphasize the importance of establishing an optimal balance between nutritional quality and physical structure in food formulation and functional product development processes. In this regard, the heat behavior of the spreadable sample of the product made of tahini was investigated using the DSC method, and the obtained results are presented in Table 5.

Spreadable tahini with 4% mono- and diglycerides the onset of crystallization temperature was measured as 21.56 °C, and the maximum crystallization temperature was determined as 16.94 °C. These values represent the temperatures at which the crystallization process begins and occurs most rapidly, indicating a moderate tendency for gelling agents to form crystalline structures in the tahini matrix. The enthalpy of crystallization was calculated as -2.297 J/g, supporting the presence of limited but homogeneously distributed crystalline regions within the product. This indicates that the product exhibits a relatively semi-solid structure and maintains its structural integrity while maintaining spreadability. During the melting phase, the onset of melting temperature was determined as 33.20 °C, and the maximum melting temperature was determined as 40.04 °C. This temperature range indicates the point at which crystallized oil structures begin to transition to the liquid phase and melting occurs at its fastest rate. A relatively narrow melting range indicates the presence of a regular and uniform crystal structure, which ensures the product melts homogeneously when heated. The enthalpy of melting was measured as 10.773 J/g, indicating the high thermal energy required to disrupt the product's crystalline network structure. This demonstrates the product's thermal stability. This thermal resistance demonstrates that the product is resistant to physical phase separation (e.g., oil seepage on the surface) and maintains its structural stability throughout its shelf life. The DSC thermogram also highlights the transition profile that occurs between 33 and 40 °C. This range allows the product to exhibit a semi-solid structure at room temperature, making it easily spreadable during consumption. The presence of well-defined crystallization and melting events indicates that the 4% mono- and diglyceride addition provides controlled thermal behavior in the tahini matrix and increases the product's thermal stability. In con-

clusion, DSC data demonstrate that mono- and diglycerides act as effective structuring agents, forming a stable crystal-oil network that optimizes the product's spreadability and thermal stability. These properties scientifically support the commercial viability of spreadable tahini products formulated using the oleogelation approach as sustainable and functional products.

4. Conclusion

This study focused on spreadable tahini formulations structured with mono- and diglycerides (MAG/DAG), stearin, and beeswax, assessing their structural, sensory, thermal, and fatty acid characteristics. The sample containing 4% mono- and diglycerides showed the most optimal spreadability properties in terms of hardness (209.38 g force) and stickiness (-69.76 g force). This formulation received the highest scores in both textural and sensory analyses and was the most appreciated product by the panelists. At the same time, the melting profile determined between 33–40 °C by DSC analysis revealed that the product can maintain its physical stability under shelf conditions by maintaining its semi-solid form at room temperature. The fatty acid profile of the developed spreadable tahini product was found to be very similar to that of traditional tahini and was found to be rich in unsaturated fatty acids that support cardiovascular health, such as oleic (38.8%) and linoleic (41.6%) acids. Although the saturated fatty acid content increased slightly with the addition of gelling agents (16.5% → 18.9%), this improved the textural stability of the product and contributed to its shelf life. The decrease in the protein ratio to 20.56% can be explained by the additives in the formulation, but this value remains above the lower limit of 20% in the Turkish Food Codex, indicating that the product maintains its nutritional adequacy.

In conclusion, this study presents original and innovative findings that contribute meaningfully to both the scientific literature and the development of functional food products within the food industry. Notably, the spreadable tahini formulation incorporating mono- and diglycerides was optimized in terms of structural integrity, shelf life, and sensory acceptance, without compromising its nutritional and functional properties. The resulting product stands out as a novel food alternative that successfully integrates high nutritional value with functional benefits while also demonstrating industrial scalability and market potential. In this context, it provides a promising model that could enhance the positioning of oil-based spreadable products in the functional food market.

Conference Presentation

Preliminary results focusing on the textural attributes (hardness and stickiness) of the spreadable tahini were presented at the 6th International Conference on Science and Technology (ICONST 2023) (Top *et al.* 2023, [54]).

Availability of Data and Materials

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

Author Contributions

DT, SC and GO designed the research study. DT, contributed to analysis, research and methodology. SC, contributed to methodology, analysis, investigation, and writing—review and editing. GO, contributed to investigation, methodology, and participated in writing—review and editing. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

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