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Research article

Assessment of rheological, qualitative and antioxidant characteristics of enriched peanut butter with date paste through shelf-life stability

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A R T I C L E I N F O

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A B S T R A C T

Over the years, concentrated efforts have been directed toward the improvement of desirable characteristics and attributes in peanut butter. This study examined the effect of rheological, antioxidant and qualitative characteristics of optimum peanut butter (including date paste and lecitin) during shelf-life. The results showed that the presence of date paste along with lecithin in optimum peanut butter improved the overall characteristics of peanut butter, including the physicochemical, microbial, mechanical, and sensory properties, compared to the control. Moreover, shelf-life had the most effect on reducing the emulsion stability, cohesiveness, antioxidant properties, and overall acceptance. In addition, the flow behavior of the emulsions was examined through the Herschel-Bulkley model using the parameters of determination coefficient, R^2, flow behavior index, n, and consistency coefficient, K ($Pa.s^n$). The presence of date paste in enriched peanut butter results in the creation of a colloidal structure among the peanut particles. This structure traps the oil, preventing it from leaving the peanut paste texture during shelf-life.

1. Introduction

Peanut (*Arachishypogaea* L.) belonging to the *Fabaceae* family, is one of the most important nuts comprising fat, protein, sugar, vitamins, minerals, and organic sources rich in calcium, thiamin, and niacin with proper bioactive properties. Therefore, the application of peanuts as a key element in the agri-food sector will be useful [1]. According to economics, peanuts are one of the most important oilseeds cultivated in tropical and subtropical regions, and due to its nutritional value and medicinal properties, it has beneficial effects on human health, thus improving the quality of human life [2]. Accordingly, a better design of agricultural products with added value to meet nutritional needs prevents the negative effects of food waste [3,4]. Date palm is one of the oldest fruit crops in the world and is primarily grown for its highly nutritious fruits, which are consumed as a staple food in many countries, especially in the Gulf region. Date contain numerous therapeutic bioactive compounds such as phenolics, flavonols, carotenoids, minerals, and vitamins. These compounds not only provide a significant amount of energy for the human body but also act as effective therapeutic agents against several diseases [5]. Peanut butter is a doughy product made from ground-roasted peanuts. It is a functional food

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composed of dense solid compounds suspended in the oil phase [6]. This product is one of the most widely used spreadable foodstuffs in the world, and its main organoleptic properties are taste and mouth feel. Moreover, the presence of phytosterol, tocopherol, and phenolic compounds in peanut butter reduces the risk of many types of cancer, heart disease, and chronic diseases [7]. Nowadays, the rate of industrial manufacturing of this product, mainly roasted and ground, is rising increasingly [1,6]. In designing the production process of a food product, the final product needs to retain its desired quality indicators, and rheological, antioxidant, and sensory properties during storage. The presence of peanut butter in cereal-based products (gluten-free cake) reduced the amount of saturated fatty acids and increased the amount of unsaturated fatty acids and oil stability. Finally, it improved the quality of the product compared to the control sample [8]. The viscosity and flow behavior of peanut butter depend on its ability to spread on a food item [9]. Liu et al. [10] investigated the rheological properties of peanut paste combined with sesame paste. The results showed that the peanut paste enriched with the sesame paste had high rheological stability and pseudoplastic behavior. It was also more acceptable than the commercial sample in terms of taste, texture, and viscosity. Wrinkler-Moser et al. [11] examined the texture and flavor properties of peanut butter stabilized with beeswax, candelilla wax, rice bran wax, or sunflower wax. They declared that these waxes improved the product texture and flavor as well as preventing phase separation in it, thus enhancing the stability of the peanut butter emulsion during storage. In another study, the taste, texture, and rheological properties of peanut butter enriched with dark chocolate were evaluated. It was revealed that the peanut butter improved the textural properties as well as increased the amount of polyunsaturated fatty acids and health benefits in the final product. Finally, its organoleptic properties and mouth feel were favorable [12]. With increasing public concerns about sugar and fat consumption, there is a great opportunity for the food industry to innovate by focusing on nutritional properties [13]. Peanuts and date have gained attention as food sources with high nutritional value, containing beneficial compounds such as phenolic compounds, vitamins, fiber, and unsaturated fatty acids. With this in mind, enriched peanut butter with date as a functional product is being introduced for evaluation [5,7]. The purpose is to assess its textural characteristics, antioxidant properties, emulsion stability, rheological characteristics, and sensory properties compared to regular peanut butter available in the market. This evaluation will be conducted over a 60 days period at temperatures of 25 and 45 °C.

2. Materials and methods

2.1. Materials and chemical reagents

For the production of peanut butter, peanut, native to Iran, was supplied from Astaneh-ye Ashrafiyeh city, Iran, and date (*Phoenix dactylifera* L. *cv Kabkab*) paste, native to Iran, was purchased from Bushehr province, Iran. Chemical reagents, including Fehling's reagent (A, B), silver nitrate (0.1 N), and chloroform, were obtained from Samchun Chemical Co. (Seoul, South Korea), and other chemical reagents and microbial culture media were bought from Merck KGaA (Darmstadt, Germany). Consumables were all purchased from local markets.

2.2. Preparation of peanut butter enriched with date paste

Peanut butter was prepared based on Gong et al. [14] with some modifications. In this method, the peanuts were roasted in a single-layer electric Binder FD53 Oven (Binder GmbH, Tuttlingen, Germany) at 150 °C for 15 min. They were selected randomly in terms of appearance and taste. Then, they were ground with a Niri N1 Nut Butter Grinder (Niri Nut Butter Maker Machine Co., Yazd, Iran) that a thick oily paste was produced. The particle size of resulted peanut butter was measured by Betersize BeVision W1 Particle Size Analyzer (Betersize Instruments Ltd., Dandong, China) the about 29 ± 1 μm. This particle size was selected to match the particle size of the commercial sample. Subsequently, the date paste (skin-free and pitted) was added to the peanut butter with a ratio of 15 percent and the resulting mixture was mixed with a Hargsun SSD10D Spiral Mixer (Hargsun Food Machinery Co., Foshan, China) for fortification. Then, the enriched peanut butter was packaged and sealed in polyethylene terephthalate (PET) containers.

2.3. Procedure for chemical and microbial analyses

Chemical analyses of the samples have been done as follows; the ash content was determined by incinerating the sample (5 g) in a muffle furnace overnight. The remainder after the incineration was then cooled and expressed as the percentage of ash [15]. The moisture content (MC) was determined by the oven drying method according to Association of Official Analytical Chemists (AOAC): samples were oven-dried at 105 °C for 3 h to have constant weight. After that, MC was expressed as the percentage of the ratio of the differences in the weight of samples before and after drying to the original weight of sample used [16]. The fat content was determined by using the soxhlet extraction method. The samples (20 g) were separately treated with hydrochloric acid to release lipids from lipid-protein complex. The digested mixture was filtered using filter paper and dried in the oven for about 2 h at 105 °C. After that, the dried sample was put in the extraction thimble, and fat was extracted using organic solvents: diethyl ether and acetone. After that, the fat extract was dried in a rotary evaporator. The remaining solvent was removed by heating the flask in the oven at 105 °C for 30 min [15]. The protein content of samples was determined using the Biuret test assay method by which the Biuret reagent was diluted in albumin: distilled water solution (1:2). Then the absorbance of this standard solution was measured at 540 nm and the standard curve was constructed. Then, the concentration of protein in samples was determined from the standard curve by extrapolation [17]. Sugar was analyzed by high-performance liquid chromatography (HPLC) [18]. Microbial analyses of samples including yeast and mold, coliform, and total microbial count were determined based on American Association of Cereal Chemists (AACC) [19]. Peanut butter samples were diluted in 0.1 % phosphate buffered saline (PBS) (BD Difco, NJ, USA). Dilutions were plated, in duplicate, onto Petrifilm plates (3M), and Yeast and Mold count plates (3M). coliform was enumerated after incubation at 44 °C, for 24 ± 2 h yeast and mold colonies were counted after incubation at 25 °C for 48–60 h. The lower and upper detection limits of the bacterial analyses were 1.30–5.00 log colony forming unit per gram (CFU/g), respectively, for coliform count plates; lower and upper detection limits for yeast and mold count plates were 1.30–4.60 log CFU/g, respectively.

2.4. Fatty acid profile determination method

Monitoring the optimal fatty acid profile of the date paste-enriched peanut butter relative to the control sample (commercial) at 25 °C was conducted using AOAC [15]. To that end, 0.5 mL petroleum ether was poured into a vial. Next, the methylating solution (sodium methoxide and methanol) and a loop of the peanut oil were added, and the vial was vortexed for 5 s. The mixture was then allowed to stand for 30 min to derivatize fatty acid methyl esters (FAME). After that 1 mL NaCl 0.8 % (w/v) was added for the proper separation of the FAME layer. In the end, 1 μL of the FAME was taken with much care from the upper layer of the vial and injected into the Agilent 5975C inert XL MSD Gas Chromatograph (Agilent Technologies, Santa Clara, USA) for analysis [20].

2.5. Textural analyses method

The hardness and cohesiveness of the peanut butter enriched with date paste, were used as a measure of its viscoelastic properties during storage at 2 temperatures of 25 and 45 °C. Texture profile analysis (TPA) was performed on the peanut butter samples using a TA.XT Plus Texture Analyzer (Stable Micro Systems, Godalming, England) equipped with a cylindrical probe, 25 mm in diameter, penetrated into the sample at a speed of 0.1 mm/s and a trigger force of 50 g. The force required to create 50 % compression, equivalent to a penetration depth of up to 4 mm and measured by drawing the force-distance curve, was considered the hardness of the peanut butter texture over 2 months [21].

2.6. Antioxidant analyses method

The total phenolic content (TPC) of the peanut butter enriched with the date paste was determined through the Folin-Ciocalteu method at 25 and 45 °C [22]. 50 μL of an appropriate dilution of the extract was added to a test tube containing 3 mL of distilled water and 250 mL of the Folin-Ciocalteu reagent. 750 μL of 20 % sodium carbonate was added. The total volume was adjusted to 5 mL with distilled water, and the mixture was mixed well. After incubation at 50 °C for 2 h, the absorbance value was read at 765 nm using a Chrom Tech CT-5600 Spectrophotometer (Chrom Tech, Taipei, Taiwan). TPC was expressed as mg gallic acid equivalent (mg GAE) and mg catechin equivalent per gr of dry peanut butter.

The 2,2-Diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging capacity of the extract was determined by the method previously described by Singh et al. [23] with some modification. 10 μL of different concentrations (0.625, 1.25, 2.50, 5.00, and 10.00 % (v/v)) of the peanut extract was added to a test tube containing 3 mL of 0.1 mM methanolic solution of DPPH. The mixture was shaken well and kept at room temperature for 2 min. After that, the absorbance value was recorded at 517 nm using a spectrophotometer. The radical scavenging capacity was reported as mg Trolox equivalent per g of dry peanut butter. Ascorbic acid, p-coumaric acid, and quercetin were used as positive controls [24].

2.7. Emulsion stability assessment method

The enriched peanut butter emulsion stability was estimated based on the amount of the oil separated from the peanut butter matrix at 25 and 45 °C. The homogenized samples were transferred to micro tubes (2 mL) and heated at 80 °C for 30 min in a water bath. Afterward, they were cooled down under running tap water and weighed before centrifugation. The blends were centrifuged at 4000 g for 10 min, and the separated oil was removed using a sampler. The percentage of the oil (w/w) released from the total oil in the emulsion was expressed as the emulsion stability [25,26]. The measurements were conducted at 25 °C in triplicate.

2.8. Rheological properties evaluation method

Rheology is the study of how materials flow and deform under stress and strain. In the food industry, rheological data is essential for understanding how ingredients function in product development, determining food texture by comparing it to sensory data, and controlling the final product. It is also important for calculating process engineering aspects related to equipment such as pumps, and mixers. The flow curves of peanut butter samples were described by Herschel-Bulkley model. The Herschel-Bulckly model is obtained as follows:

$$\tau = \tau_0 + k\,\dot{\gamma}n$$

where, τ_0 is yield stress (Pa), k is consistency index (Pa.s), and n is the dimensionless flow behavior index [27]. These rheological parameters, were measured at 25 and 45 °C using Brookfield PV3T Viscometer (BROOKFIELD AMETEK, Middleboro, USA) equipped with a sampler and a water bath for temperature control. To perform the test, the SC-27 rotating spindle was used at 1–8 rpm in 2 stages of rising (increasing shear rate) and falling (decreasing shear rate) during storage for 2 samples (control sample in comparison with the optimal one).

2.9. Sensory evaluation method

A total of 10 trained panelists (6 female, and 4 male) took part in a descriptive analysis of peanut products. They were selected based on the following criteria: a) aged between 22 and 40, b) non-smokers, c) without peanut butter allergies, d) consuming roasted peanuts and peanut products at least twice a week, e) available for all sessions, f) interested in participating, and g) able to communicate observations about the product. The panelists were trained and calibrated in sessions for evaluating peanut pastes. During the sample evaluation, 10 g of peanut butter samples were placed into plastic cups with lids labeled with random 3-digit numbers. Each panelist received 4 samples, with 3 replicates for each analysis, each day. These samples included 2 date-enriched peanut butter and 2 commercial peanut butter obtained from the market. The samples were kept at temperatures of 25 and 45 °C, corresponding to days 1, 14, 30, 45, and 60 of the shelf-life. The samples were presented to the panelists in random order during the 5 test days, accompanied by warm water and paper ballots on a plastic tray. Panelists were instructed to consume the whole sample (a teaspoon of peanut paste) and rinse their mouths with warm water between samples to minimize any residual effect. They evaluated the sensory attributes of the peanut paste samples using a 5-point hedonic scale (ranging from 1 to 5 from lowest to highest), for attributes including general appearance, softness, aroma and taste, crumb color, mouth feel, and overall acceptance (OA) [28]. The purpose of this analysis was to examine the sensory characteristics of enriched peanut butter and compare it with the commercial sample in terms of OA.

2.10. Statistical analysis procedure

The peanut butter preparation and all the experimental procedures were performed in triplicate (n = 3). The data were subjected to analysis of variance (ANOVA) using SAS software version 9.1. Mean comparisons were performed using Duncan's test to examine whether the differences among the treatments and the storage time were significant at $P < 0.05$.

3. Results and discussion

3.1. Chemical and microbial properties

The results of the chemical analyses of the peanut butter enriched with date paste after production on day 1 compared to the control sample are summarized in Tables 1 and 2, respectively. According to the results obtained, the enriched peanut butter exhibited higher values of fat followed by protein compared to the control sample. Also, the analysis of the results obtained from the microbial analysis of the enriched peanut butter on the first day of production compared to the control sample showed that the microbial properties of the enriched peanut butter are similar to the control sample in terms of coliforms, mold and yeast. Furthermore, in terms of total microbial count, the enriched peanut butter has a more suitable condition on the first day of preparation.

3.2. Fatty acid profile evaluation

Table 3 shows the fatty acid profile of the optimal peanut butter compared to the control sample during storage. The ratio of the total unsaturated fatty acids to saturated fatty acids in the enriched peanut butter (optimal sample) on days 1 and 60 was 2.65 and 0.81, respectively. Additionally, for the control sample, these values on days 1 and 60 were 2.37 and 0.77, respectively. This evaluation showed that the total unsaturated fatty acid content of the optimal sample was higher than that of the control sample during storage. The content of oleic acid, as the major fatty acid in enriched peanut butter, was significantly higher in the optimal sample compared to the control sample during storage. Therefore, the health benefits of high oleic acid as an unsaturated fatty acid in enriched peanut butter were observed. Butter will reduce low-density cholesterol, improve blood lipid profile, and decrease the risk of cardiovascular diseases such as heart attack and atherosclerosis. These fatty acids are effective in reducing abdominal fat. Polyunsaturated fatty acids include omega-3 and omega-6 fatty acids. Alpha-linolenic acid is an omega-3 fatty acid that prevents blood pressure, cardiovascular diseases, and blood clotting [29]. Moreover, the amount of lipids in date is relatively small compared to carbohydrates [30]. Despite the low lipid content, date fruit contributes to the high quality of essential fatty acids, which are vital for human health [31].

3.3. Textural properties evaluation

The results of measuring the hardness of the enriched peanut butter at 2 temperatures of 25 and 45 °C during storage are shown in Fig. 1 (A&B). The results showed that the hardness of the peanut butter significantly increased over time ($P < 0.05$). In addition, by comparing the mean hardness values of the optimal and control samples, a significant trend was evident in each day of storage. This

Table 1
Chemical & microbial characteristics of enriched peanut butter at first day of preparation.

Yeast & Mold	Coliform	Total microbial count (Cfu/g)	Protein (%)	Salt (%)	Ash (%)	Sugar (% sucrose)	Fat (%)	Moisture (%)
10	negative	26000	23.17 ± 0.27	0.02 ± 0.01	2.39 ± 0.21	3.74 ± 0.16	49.28 ± 0.29	0.69 ± 0.07

Table 2
Chemical & microbial characteristics of control peanut butter.

Yeast & Mold	Coliform	Total microbial count (Cfu/g)	Protein (%)	Salt (%)	Ash (%)	Sugar (% sucrose)	Fat (%)	Moisture (%)
10	negative	33000	21.20 ± 0.23	0.03 ± 0.00	2.01 ± 0.04	2.63 ± 0.05	57.11 ± 0.24	0.51 ± 0.03

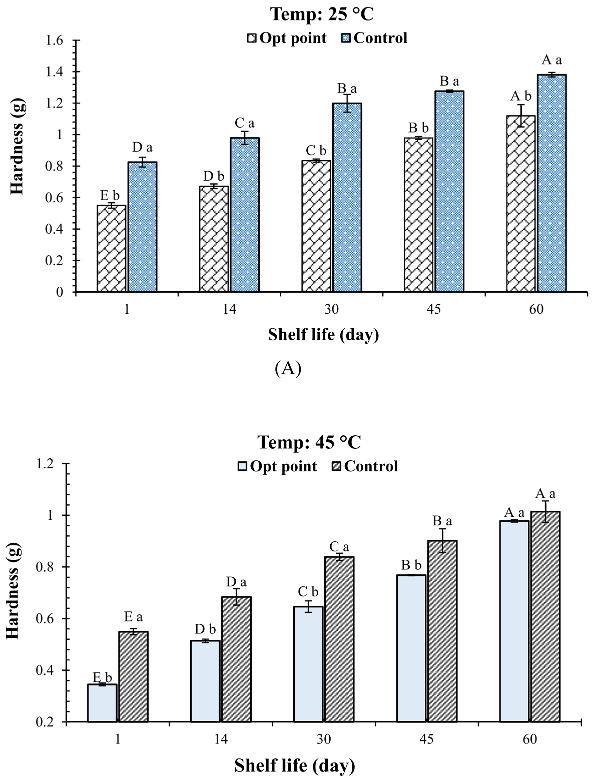
Table 3
The result of fatty acid profile of optimal peanut butter during shelf-life in comparison to the control sample at 25 °C.

FFA (Control)	Shelf-life (day)					FFA (OPT point)
	1	14	30	45	60	
C14:0	1.75 ± 0.23 0.70 ± 0.11	2.06 ± 0.22 1.84 ± 0.22	2.05 ± 0.03 1.85 ± 0.17	2.11 ± 0.023 1.89 ± 0.32	2.15 ± 0.22 1.93 ± 0.32	C14:0
C14:1	0.93 ± 0.09 0.90 ± 0.15	0.82 ± 0.13 0.83 ± 0.17	0.78 ± 0.11 0.77 ± 0.23	0.79 ± 0.14 0.74 ± 0.11	0.74 ± 0.25 0.66 ± 0.21	C14:1
C16:0	15.30 ± 0.60 12.11 ± 0.18	30.80 ± 0.65 13.69 ± 0.20	32.65 ± 0.70 32.44 ± 0.42	33.12 ± 0.72 32.67 ± 0.42	34.22 ± 0.70 33.99 ± 0.47	C16:0
C16:1	1.40 ± 0.13 0.60 ± 0.26	1.26 ± 0.34 1.25 ± 0.32	1.20 ± 0.21 1.13 ± 0.28	1.16 ± 0.15 1.04 ± 0.26	1.13 ± 0.23 1.01 ± 0.19	C16:1
C18:0	2.72 ± 0.22 3.23 ± 0.15	2.96 ± 0.13 2.65 ± 0.16	3.20 ± 0.18 2.87 ± 0.14	3.29 ± 0.24 2.91 ± 0.23	3.36 ± 0.21 3.01 ± 0.34	C18:0
C18:1	39.67 ± 0.65 41.11 ± 0.80	28.63 ± 0.57 38.23 ± 0.75	24.58 ± 0.43 26.91 ± 0.50	23.01 ± 0.65 25.34 ± 0.64	22.12 ± 0.52 24.22 ± 0.65	C18:1
C18:2	22.41 ± 0.90 25.07 ± 0.32	18.34 ± 0.92 20.06 ± 0.29	16.09 ± 080 17.88 ± 0.21	15.02 ± 0.70 17.04 ± 0.22	14.80 ± 0.52 16.45 ± 0.20	C18:2
C18:3	0.71 ± 0.21 0.80 ± 0.23	0.67 ± 0.26 0.64 ± 0.16	0.62 ± 0.16 0.60 ± 0.12	0.52 ± 0.11 0.55 ± 0.10	0.34 ± 0.12 0.30 ± 0.09	C18:3
C20:0	1.91 ± 0.26 1.90 ± 0.12	2.13 ± 0.26 2.01 ± 0.15	2.24 ± 0.47 2.05 ± 0.11	2.30 ± 0.45 2.09 ± 0.10	2.35 ± 0.27 2.10 ± 0.13	C20:0
C20:1	3.52 ± 0.10 3.15 ± 0.14	3.26 ± 0.17 2.92 ± 0.22	3.10 ± 0.25 2.86 ± 0.32	3.05 ± 0.22 3.62 ± 0.31	2.93 ± 0.20 1.07 ± 0.28	C20:1
C22:0	2.90 ± 0.26 2.89 ± 0.29	3.23 ± 0.15 3.05 ± 0.25	3.41 ± 0.36 3.15 ± 0.11	3.44 ± 0.21 3.20 ± 0.14	3.58 ± 0.17 4.00 ± 0.10	C22:0
C22:1	1.54 ± 0.12 1.38 ± 0.20	1.46 ± 0.23 1.30 ± 0.14	1.39 ± 0.15 1.24 ± 0.12	1.39 ± 0.14 1.17 ± 0.16	1.31 ± 0.20 1.03 ± 0.22	C22:1
C24:0	2.73 ± 0.23 2.08 ± 0.40	3.05 ± 0.26 2.73 ± 0.35	3.21 ± 0.35 2.88 ± 0.20	3.32 ± 0.38 2.97 ± 0.19	3.37 ± 0.26 3.01 ± 0.24	C24:0
C24:1	0.20 ± 0.12 0.19 ± 0.05	0.18 ± 0.07 0.18 ± 0.06	0.17 ± 0.05 0.16 ± 0.04	0.17 ± 0.07 0.15 ± 0.07	0.16 ± 0.07 0.14 ± 0.04	C24:1

can probably be attributed to the change in the fatty acid profile and the increase in the unsaturated fatty acids content, as well as the consistency and hardness of the peanut butter enriched with the date paste. Any change in the composition of the fat phase in peanut butter can cause texture changes [32]. Indeed, the presence of sweetening compounds such as date and emulsifiers like lecithin in the peanut butter formulation increases the MC of the product during storage, especially at higher temperatures. This makes the product softer in texture, especially at higher temperatures. As a result, the temperature of 45 °C produced a softer texture than 25 °C during storage. The studies conducted by Shakerardekani [7], Gamlı and Hayoglu [33], and Muego-Gnanasekharan and Resurreccion [34] confirm our findings.

Cohesiveness is defined as the strength of the internal bonds within the body of the product, suggesting that the internal bonds of the optimal sample were stronger than those of the control. Furthermore, the cohesiveness values of the optimal and control samples followed a downward trend during storage. The effect of the date paste on textural properties is presented in Fig. 2. In fact, enriching the peanut butter with the date paste significantly ($P < 0.05$) increased the cohesiveness compared to the control sample. There was a significant difference between the cohesiveness values of the optimal and control samples on each day of storage ($P < 0.05$), especially in the first month.

The research conducted by Mazaheri-Tehrani et al. [35] confirms our finding. By creating porosity, the presence of suspended compounds such as date paste in butter matrix prevents the binding of fat crystals and the development of a homogeneous hardness. Accordingly, by aeration and correct mixing of the date paste powder or any other ingredient on an industrial scale, the excessive weakening of the hardness and cohesiveness of the network is prevented. It inhibited the reconstruction of the network structure and crystals reconnection [36]. In another study, Alplaslan and Hayta [37] found that adding grape molasses to sesame paste creates a colloidal structure among the sesame particles. This structure traps the oil, preventing it from leaving the sesame paste texture during shelf-life. As a result, the product's texture becomes soft, which aligns with the findings of our study.



(B)

Fig. 1. Evaluation of hardness of optimal peanut butter during shelf-life in comparison to the control sample at (A) 25 °C and (B) 45 °C. Results are expressed as mean values of triplicates ± standard deviation. a-d Different superscript letters in each shelf-life among the samples denote signifcant differences ($P < 0.05$). A-B-C Different superscript letters in the during shelf-life among the samples denote signifcant differences ($P < 0.05$).

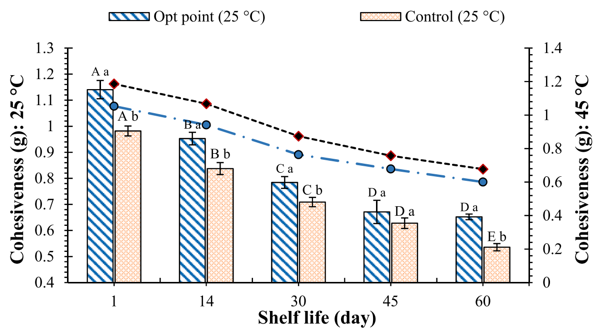


Fig. 2. Evaluation of cohesiveness of optimal peanut butter during shelf-life in comparison to the control sample at 25 °C and 45 °C. Results expressed as mean values of triplicates ± standard deviation. a-d Different superscript letters in the each shelf-life among the samples denote signifcant differences ($P < 0.05$). A-B-C Different superscript letters in the during shelf-life among the samples denote signifcant differences ($P < 0.05$).

3.4. Antioxidant properties evaluation

The results obtained from the evaluation of TPC for the 2 samples (optimal and control) are illustrated in Fig. 3 (A). Due to its high water absorption capacity and reduction in its free water activity, the optimal sample had the highest TPC. The results showed that the TPC of the peanut butter decreased significantly over time ($P < 0.05$). Furthermore, the phenolic compounds were more released at 45 °C than at 25 °C. Liazid et al. [38] reported similar results which indicated that increasing the temperature of the system accelerated

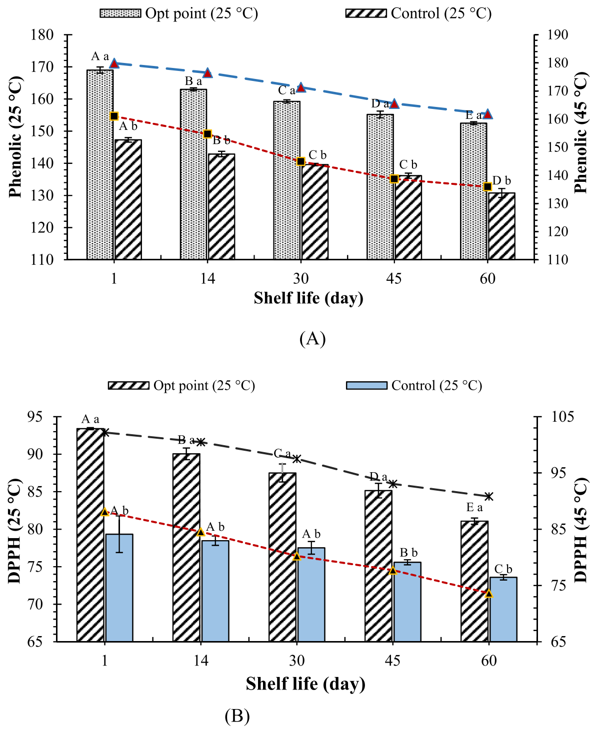


Fig. 3. (A) Evaluation of phenolic content of optimal peanut butter during shelf-life in comparison to the control sample at 25 °C and 45 °C (B) Evaluation of DPPH content of optimal peanut butter during shelf-life in comparison to the control sample at 25 °C and 45 °C.

the release of phenolic compounds and their dissolution in the solvent. Since the extraction temperature was high, there was a possibility that some phenolic compounds with antioxidant properties, such as resveratrol, present in peanuts, could be decomposed due to heat sensitivity [39]. In addition, the presence of oxygen in the environment easily affected some oxygen-sensitive com-pounds and caused them to oxidize. Phenolic compounds were extracted from the peanut skin with the assistance of microwaves. The results showed that the destruction of the phenolic compounds was intensified with the simultaneous increase in the power and time of the thermal process [40]. The ANOVA results for the DPPH content of the 2 samples (optimal and control) with the color change of the reaction solution from dark purple to light yellow expressed as mg Trolox equivalent (TE)/g of dry peanut butter are depicted in Fig. 3 (B). The results indicated that the DPPH content of the peanut butter significantly ($P < 0.05$) decreased over time [22]. Additionally, the effect of the radical scavenging capacity was much better at 45 °C than at 25 °C. By increasing the system temperature, high power accelerates the release of phenolic compounds and their dissolution in the solvent, in addition to raising the radical scavenging capacity [38,41]. Chuenchom et al. [22] declared that the antioxidant capacity of ascorbic acid, determined by the scavenging of DPPH radicals, was approximately 8, 9, and 7 times greater than those of Spanish, Valencia, and Virginia peanuts, respectively. Singh et al. [42] extracted phenolics from potato skin using microwaves and evaluated the DPPH free radical scavenging activity of the extract. The results showed that a rise in temperature brought about the destruction of heat-sensitive compounds and a reduction in the antioxidant activity.

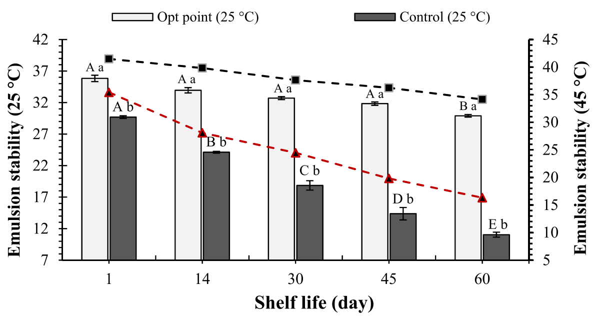


Fig. 4. Evaluation of emulsion stability of optimal peanut butter during shelf-life in comparison to the control sample at 25 °C and 45 °C.

3.5. Emulsion stability evaluation

The emulsion stabilities of the 2 samples (optimal and control) are illustrated in Fig. 4. Mean comparison using Duncan's multiple-range test indicated that the emulsion stability of the peanut butter decreased over time, which was not significant at $P < 0.05$. It was also found out that enrichening the peanut butter with the date paste significantly ($P < 0.05$) raised the emulsion stability, compared to the control sample. Furthermore, the temperature of 45 °C had a much better effect on the emulsion stability than 25 °C.

The emulsion stability of natural peanut butter during storage has remained a challenge for peanut butter producers. MohdRozalli et al. [43] claimed that the high moisture accumulation in microwave-pre-treated peanut butter (MPPB) along the storage duration might be due to the lack of stabilizers to prevent oil separation during storage.

Emadzadeh et al. [44] studied the effect of storage time on the emulsion stability and the oiling-off percentage during 3 months of storage. The results demonstrated that no effect of composition was observed on the emulsion stability at all, and they were all accepted as stable samples. Habibi Najafi and Alaee [45] reported that the emulsion stability of sesame paste/date syrup blends increased at higher levels of the date syrup.

3.6. Rheological evaluation

The results of measuring the rheological properties of the peanut butter at 2 temperatures (25 and 45 °C) during storage (2 months) are presented in Table 4. The results showed that the K value (pa.s) increased over time. In general, peanut butter has non-Newtonian pseudoplastic behavior. Therefore, in this research, the relationship between shear stress and shear rate was investigated through the Herschel-Bulkley model. Indices n and K are considered to be flow behavior index and consistency coefficient, respectively, which are partly related to the product's viscosity [46].

Razavi et al. [47] reported similar results according to which pistachio butter was a semi-solid fluid, and the relationship between shear stress and shear rate was non-linear, non-Newtonian, and pseudoplastic along with yield stress. Abu-Jdayil et al. [48] applied the Herschel-Bulkley model to describe the flow behavior of ground sesame butter which showed a pseudoplastic behavior. The R^2 of this model was found to be in the range of 0.952–0.999, which indicated the model's suitability and explained the flow behavior of the samples. Sengul et al. [49] assessed the Herschel-Bulkley models concerning rheological flow behavior. The results revealed that the models could determine the best rheological properties with determination coefficients of above 98 %. Changes in flow behavior occur due to the rise in temperature and the duration of storage.

3.7. Sensory evaluation of enriched peanut butter

Sensory evaluation of date-enriched peanut butter (optimal sample) compared to commercial peanut butter (control sample) including general appearance, softness, aroma and taste, crumb color, mouthfeel, and OA at 2 temperatures of 25 and 45 °C, and in The length of the 60 days shelf-life is shown in Figs. 5–10 (A&B) respectively. The statistical analysis of the mean results obtained from the paper ballots of the panelists showed a similar downward trend for both investigated variables (temperature and shelf-life) in the case of each of the sensory characteristics, However, the optimal sample showed a notably significant trend ($P < 0.05$). The main reason for the difference in the sensory characteristics evaluated in this research for the optimal sample and the control is due to the difference in lipid content, MC, and different amounts of carbohydrates, which is due to the presence of date in the composition of the optimal sample which is consistent with the results of Younas et al. [5], Capanoglu and Boyacioglu [50], and Velasco et al. [51]. The presence of date in the optimal sample, on the one hand, creates a light brown color and a darker appearance than the control sample, which indicates better popularity than the control sample (Fig. 5 (A&B) and Fig. 8 (A&B)), which this trend is maintained for both temperatures during the shelf-life, which is consistent with the results of Younas et al. [5]. The analysis of the softness characteristic of the optimal sample showed that the texture of the optimal peanut butter was relatively softer than the texture of the control sample and this trend was maintained during the storage period at both temperatures. In justification of this process, it can be said that the higher moisture ratio in the optimal sample due to the presence of date in the short term creates a softer, semi-dry texture compared to the control sample, which was consistent with the results of the research by Younas et al. [5]. Additionally, the analysis of the mean results

Table 4
Herschel-Bulkley model parameters for optimal peanut butter during shelf-life in comparison to the control sample at 25 °C and 45 °C.

Shelf-life (day)	Sample	T: 25 °C			T: 45 °C		
		R^2	n	K ($Pa.s^n$)	R^2	n	K ($Pa.s^n$)
First day	Control	0.967	0.401	82.49	0.975	0.419	84.68
	Optimal	0.932	0.346	64.908	0.929	0.351	68.21
14th day	Control	0.977	0.417	85.21	0.984	0.422	87.26
	Optimal	0.938	0.352	70.04	0.932	0.361	71.05
30th day	Control	0.980	0.419	87.62	0.989	0.449	89.14
	Optimal	0.942	0.361	70.16	0.956	0.367	73.63
45th day	Control	0.983	0.428	89.19	0.990	0.452	91.24
	Optimal	0.942	0.372	71.08	0.965	0.371	76.17
60th day	Control	0.991	0.462	90.22	0.996	0.469	97.16
	Optimal	0.984	0.379	77.82	0.984	0.386	85.29

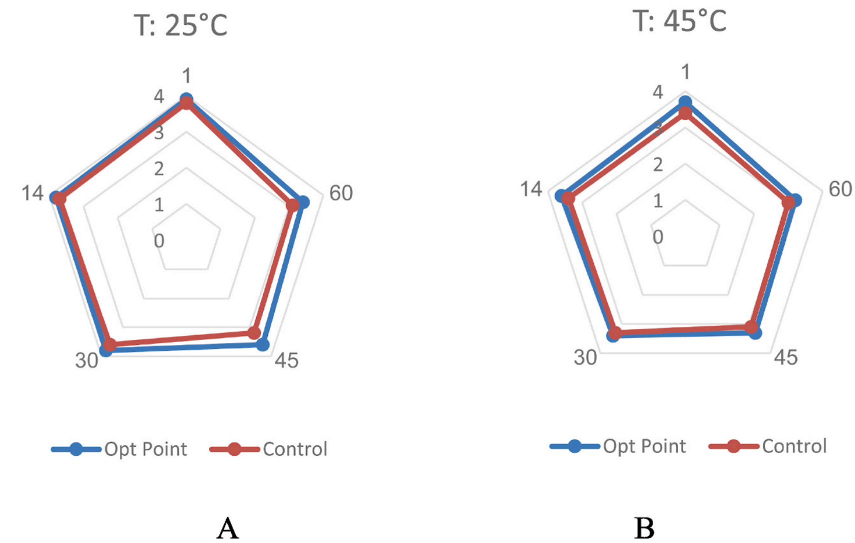


Fig. 5. Evaluation of general appearance of optimal peanut butter during shelf-life in comparison to the control sample at (A) 25 °C and (B) 45 °C.

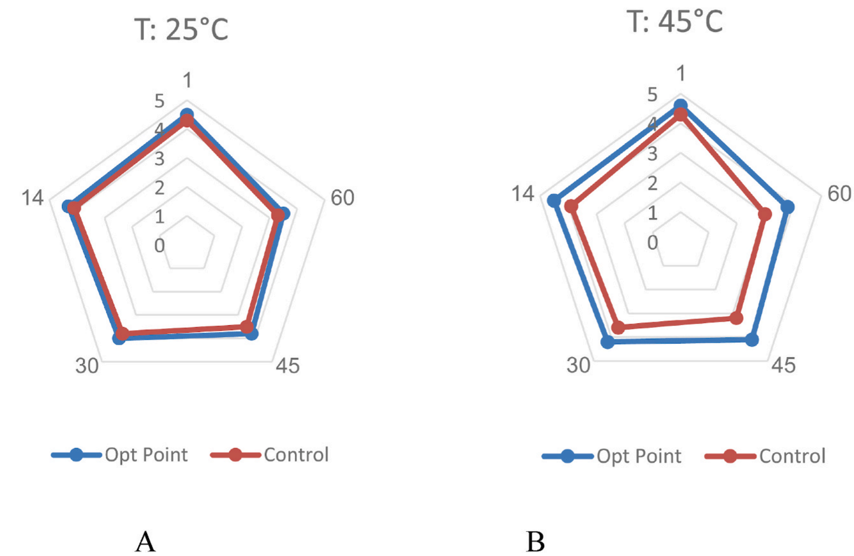
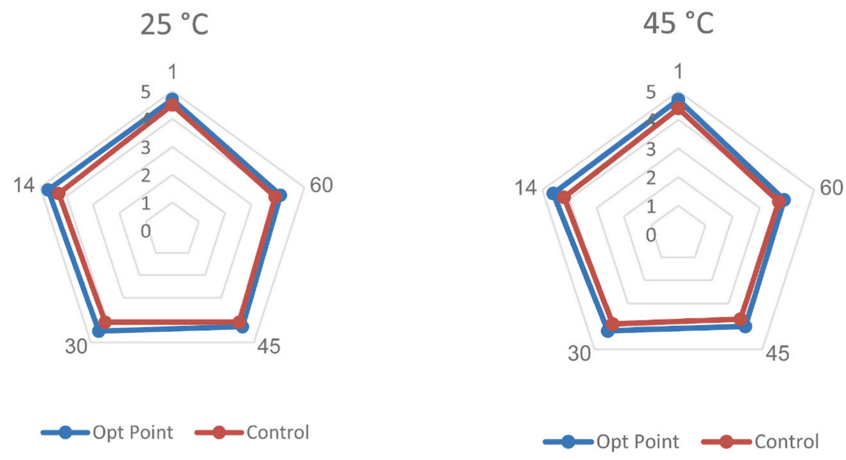


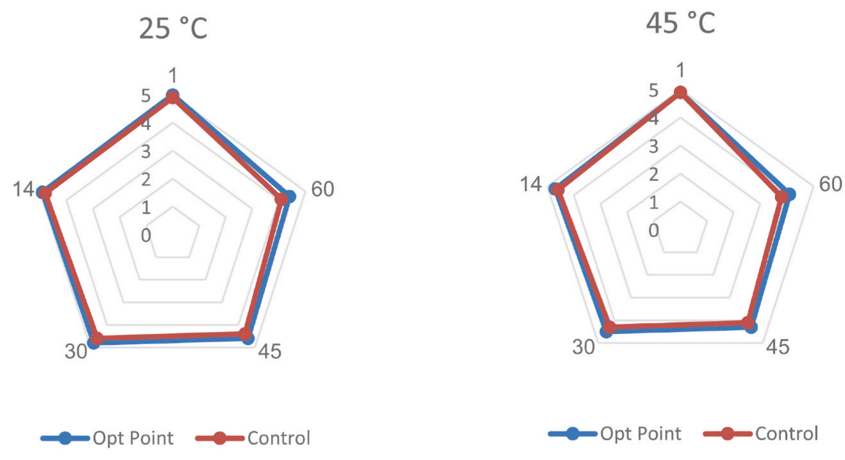
Fig. 6. Evaluation of softness of optimal peanut butter during shelf-life in comparison to the control sample at (A) 25 °C and (B) 45 °C.

of aroma and taste along with mouthfeel (Fig. 7 (A&B) and Fig. 9 (A&B)) showed that aroma and taste along with mouthfeel are the most effective sensory characteristics that have been noticed by the panelists. In general, the secondary oxidation of lipids in peanuts along with the rancidity of sugars in date were determined as influencing factors on aroma and taste, and mouthfeel during the shelf-life at 2 investigated temperatures. Since the date-enriched peanut butter in the same weight ratio as the commercial sample in the sensory evaluation, contains less fat and more simple sugar compounds compared to the commercial sample, therefore, despite the decrease in sensory characteristics during the shelf-life period, Apparently, the factor of secondary lipid oxidation and the creation of unpleasant aldehyde and ketone compounds has prevailed over the rancidity of sugar compounds, which has led to better mean results for the optimized sample, which is consistent with the results of Gamli and Hayoglu [33]. The trend of OA for the sensory properties of the 2 peanut butter samples (optimal and control) at 2 temperatures (25 and 45 °C) during storage (2 months) is denoted in Fig. 10 (A&B). The results of mean comparison with the Duncan's multiple-range test showed that the OA of the produced peanut butter significantly ($P < 0.05$) declined as the storage time increased. The optimal peanut butter had a higher OA than the control sample. The presence of the date paste in the peanut butter formulation restrained moisture loss and improved the softness of the texture. Moreover,



A B

Fig. 7. Evaluation of aroma & taste of optimal peanut butter during shelf-life in comparison to the control sample at (A) 25 °C and (B) 45 °C.



A B

Fig. 8. Evaluation of crumb color of optimal peanut butter during shelf-life in comparison to the control sample at (A) 25 °C and (B) 45 °C. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

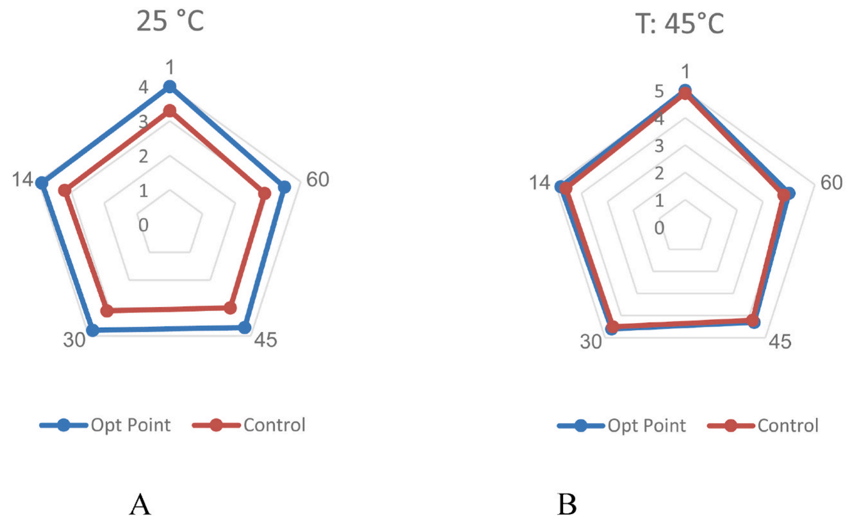


Fig. 9. Evaluation of mouth feel of optimal peanut butter during shelf-life in comparison to the control sample at (A) 25 °C and (B) 45 °C.

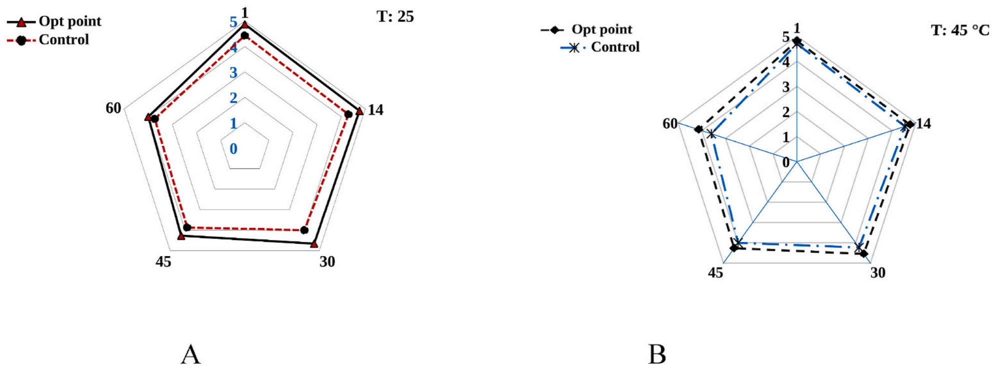


Fig. 10. Evaluation of overall acceptance of optimal peanut butter during shelf-life in comparison to the control sample at (A) 25 °C and (B) 45 °C.

the effect of 45 °C during storage was much better than that of 25 °C. The studies conducted by Shakerardekani [7], and Nepote et al. [52] confirm our findings.

4. Conclusions

The present study aimed to enhance the quality, rheological, and antioxidant properties of peanut butter. The rising concerns about fat and sugar consumption have presented a challenge and an opportunity for the food industry to innovate with a nutritional focus. Peanuts and date are rich in beneficial compounds such as phenolic compounds, vitamins, fiber, and unsaturated fatty acids, making them valuable food sources. This study introduced enriched peanut butter with date (optimal sample) and compared its textural characteristics, antioxidant indices, emulsion stability, rheological properties, and sensory evaluation to regular peanut butter available in the market (control sample) over a 60 days period at temperatures of 25 and 45 °C. It was concluded that all the indicators investigated in this study showed a downward trend during the shelf-life period, but the optimal sample demonstrated significantly better quality compared to the control sample. As the popularity and market for peanut butter continue to grow, more research is needed for the production of functional foods such as peanut butter. While past studies have focused on peanut and peanut butter production, there's a lack of research on enriched peanut butter. Therefore, it is suggested that further research should be conducted to develop other types of peanut butter products with extended shelf-life.

5. Future recommendations

- Optimizing the formulation of extra-beneficial peanut butter using other variables such as beeswax, sunflower oil, and different proportions of oleogel compounds on an industrial scale
- Using indigenous hydrocolloids as an additive in peanut paste formulation in order to reduce oil leakage and create a stable structure during the shelf-life period on an industrial scale.

- Using the Pickering emulsion system in the structure of peanut butter paste to improve the rheological, textural, and sensory properties during the shelf-life.

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Ethics statement

The authors declare that the results of the current sensory evaluation did not pose any safety and nutritional risks for the panelists and it was done with the informed consent of the participants.

Data availability statement

Data included in article/supp. material/referenced in article.

CRediT authorship contribution statement

Seyedeh Faezeh Safaei: Writing – review & editing, Writing – original draft, Software, Investigation. **Sara Jafarian:** Validation, Project administration, Methodology, Data curation, Conceptualization. **Mojtaba Masoumi:** Software, Data curation. **Mehdi Sharifi Soltani:** Validation. **Leila Roozbeh Nasiraie:** Supervision, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e37602.

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