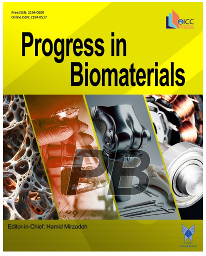

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The Development, Characterization, Sensory Evaluation, and Consumer Analysis of An Innovative Fat Replacer Based on Bigel Containing Walnut Oil to Replace Palm Oil in Low-Fat Chocolate Spread

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Original Research

Abstract:

Chocolate spread, as a high-fat product, is a candidate for reformulation due to health concerns associated with its high saturated fat content. The used fat significantly influences the sensory attributes, texture, spreadability, and stability properties of spreads. This study introduces a novel bigel-based fat replacer, developed from walnut oil, rice bran wax (oleogel phase), and guar gum (hydrogel phase), to replace palm oil in low-fat chocolate spread formulations. Low-fat spread formulations were developed using 25, 50, 75, and 100% bigel replacement with palm oil. This study investigated the physicochemical properties (oxidative stability, oil binding capacity, spreadability, texture, and color), sensory evaluation, and consumer test of the developed spread. The results demonstrated that the incorporation of bigel in the spread resulted in higher oxidative stability (6.32 meq/kg) and better oil binding capacity (99.91%). The spread containing higher content of bigel showed lower hardness and higher cohesiveness and adhesiveness. The samples containing 25% bigel had spreadability and firmness close to the control sample containing 100% palm oil. The substitution of bigel led to higher brightness values in spreads. The spreads with 75% bigel were evaluated as the most accepted sensory characteristics regarding creamy texture and flavor. Overall, the results indicate that the developed bigel-based replacer successfully mimics the rheological and sensory properties of traditional fat and could be recommended for use in the formulation of low-fat chocolate spread.

Keywords:

Bigel; Low-fat; Chocolate; Spread; Palm oil; Walnut oil; Fat replacer

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1. Introduction

Chocolate spreads are an affordable alternative to chocolate, and their sensory and physicochemical properties are significantly affected by their fat content (Acan et al., 2022; Marra et al., 2023). Generally, full-fat spreads typically contain 80% fat, while reduced-fat and low-fat spreads contain 60% and 40% fat, respectively (Manzocco et al., 2014; Baltuonyte et al., 2022). In chocolate spread, the oil phase could be composed of Cocoa butter or plastic fats such as lauric acid, coconut oil, and palm oil. These fats influence the stability and spreadability of spreads through the partial crystallization of high-melting triglycerides (Puscas and Chende, 2020; Fernandes Almeida et al., 2024; Trapp et al., 2024). Palm oil, due to its low cost and availability, is often substituted for cocoa butter (Manzocco et al., 2014). However, its high levels of saturated and trans fats increase the risk of coronary artery disease (Li et al., 2024). To reduce these risks, oils rich in unsaturated fats (UFAs) are chosen for use in healthy spreads (Fernandes Almeida et al., 2024). Unsaturated fats negatively affect the sensory and physicochemical properties, stability, and spreadability of chocolate products (Baltuonyte et al., 2022; Marra et al., 2023). However, innovative approaches, such as the development of hydrogels, oleogels, emulsion gels, and bigels have been proposed to structure unsaturated fats to mimic semi-solid saturated fats (Quilaqueo et al., 2022). Natural gums as substitutes for solid fats, offer easy spreadability and miscibility but lack the same nutritional properties as solid fats (Silva et al., 2023; Martins et al., 2019). The use of agar hydrocolloid as a fat replacer in chocolate has been reported to reduce fat content in the chocolate by up to 80% (Skelhon et al., 2013). Gelatin from chicken by-product can replace up to 75% of the fat in chocolate spread while maintaining satisfactory spreadability (Almeida and Lannes, 2017). Espert et al. (2020) investigated the use of cellulose ether-based emulsion gels containing 20% fat, as a fat replacer in cocoa cream. However, these gels lacked the necessary plasticity and spreadability for fatty products, and they reduced aroma and flavor release. The limitations of using hydrogels have spurred interest in alternative fat-replacement structures with enhanced properties. In this regard, oleogels are designed to mimic the characteristics of solid fats and offer a desirable texture and structure (Li et al., 2024; Banas et al., 2024; Francavilla et al., 2023). Bigels, a semi-solid system, can overcome drawbacks associated with their biphasic nature (Francavilla et al., 2023; Fernandes Almeida et al., 2024; Shakouri et al., 2024a). Developed Bigels have been widely applied not only in the cosmetic and pharmaceutical industries but also in the food industry (Shakouri et al., 2024b). Li et al. (2024) incorporated bigels into spread formulations, Cui et al. (2022) used bigels as cream analogs, in Nutter et al. (2023) study plant-based bigels introduced as commercial solid-fat substitutes in short-dough bakery products. Their unique structural properties and their polyunsaturated fatty acids contribute to reducing overall and harmful fat content (Vershkov and Davidovich-Pinhas, 2023; Chao et al., 2024). The spreading ability of bigel makes them an attractive choice for healthy formulations and cream analogs (Baltuonyte et al., 2022; Cui et al., 2022). Additionally, bigels can improve mechanical properties such as flexibility, structural stability, and shelf life (Silva et al., 2022). Bigels have lower fat content than traditional fats, thereby allowing them to reduce the total fat content of the finished product (Silva et al., 2022). Additionally, bigels, which are made from unsaturated fats, are considered healthy fat replacers and are expected to provide desired physicochemical and organoleptic properties (Francavilla et al., 2023). So, the combination of the structural stability, low fat content, and the biphasic design in bigel makes it directly applicable to the formulation of fat-continuous foods such as chocolate spreads (Li et al., 2024). The objective of the present study was to investigate the use of a developed bigel containing walnut oil-based oleogel and a guar gum-based hydrogel as a fat replacer to replace palm oil in a chocolate spread formulation. The physicochemical, sensory evaluation, and consumer test were conducted on spread samples.

2. Material and methods

2.1 Materials

Guar gum was procured by Merck Company (India), palm oil (melting point 32.34 ± 0.10 °C) was purchased from (Cargill, Malaysia), Rice bran wax was obtained by Distribution GmbH. Inc (Hamburg, Germany). Extra virgin walnut oil with peroxide values ranging from 0.23 to 0.36 meq O2/kg oil (Kamjed, Iran), sugar (Golha, Iran), and cocoa powder (Farmand, Iran) were procured from a local market in Shahrood, Iran. All chemicals used in the study were of analytical grade and purchased from Merck (Darmstadt, Germany).

2.2 Bigel preparation

The cold emulsification method was used to prepare the bigels. The oleogel phase made using rice bran wax (9%, w/w) dissolving in walnut oil at 500 rpm for 15 min at 80 °C to obtain complete solubilization (Saffold and Acevedo, 2021). A 9% concentration is optimal, as lower levels hinder network formation and higher levels cause excessive hardness or instability. The hydrogel phase was prepared using guar gum (1.8%) was dispersion in water by stirring at 1000 rpm for 60 min at 70 °C (Singh et al., 2014). Then the bigel was prepared by mixing the hydrogels and oleogel phases at ratio of 70:30 at room temperature (25 °C) using an overhead stirrer (Heidolph, Germany) at 600 rpm for three minutes. The final bigel (a homogeneous white mixture) was stored in a refrigerator (4 °C) for 24 h.

2.3 Spread preparation

The spread was prepared according to method of Tirgarian et al. (2023) containing sugar (50%), fat (palm oil or bigel) (36%), cocoa powder (14%), and vanillin (0.1%). Melanger (Premium, China) was used to mix and reduce the size of the powdered ingredients. At first, palm oil was heated at 55 °C to obtain a homogenous fat phase. The spread samples prepared by adding bigel based on walnut oil–rice bran wax oleogel and a guar gum hydrogel to the chocolate spread mixture at ratio of 25%(SB4), 50% (SB3), 75% (SB2), and 100% (SB1) replacement by palm oil phase (Table 1). All the samples were mixed in a mixer (IKA, Germany) for 2 min at 150 rpm without temperature selection to ensure a uniform and homogeneous spread texture. All spread samples were stored in a cool and dry condition for 48 h.

Table 1. The formulation of chocolate spread samples.

Sample	Fat (36%)		Sugar %	Cocoa powder %
	Bigel %	Palm oil%		
SB1	100	0	50	14
SB2	75	25	50	14
SB3	50	50	50	14
SB4	25	75	50	14
control	0	100	50	14

2.4 Oxidative stability

The process of measuring peroxide values was carried out at intervals from zero time until 6 months using the procedure outlined by Quilaqueo et al. (2022) and Samui et al. (2021). Firstly, Fat was extracted of samples, and the peroxide value (PV) was measured on the clear oil phase. To begin, a 30 mL mixture of acetic acid and chloroform in a 3:2 ratios was used to dissolve five grams of the sample. The mixture was stirred for about half a minute to dissolve the oil in the solvent. Next, by adding 0.5 mL of KI the mixture placed in a dark environment for about a minute for the reaction to take place. After that 30 mL of distilled water added to sample and titrated with sodium thiosulphate solution using 1% starch as indicator. Finally, the peroxide value was determined using the following equation:

$$\text{Peroxide value} = \frac{N \times (V - V_0)}{W} \times 100 \quad (1)$$

N: The normality (meq/mL) of sodium thiosulphate., V: The volume (mL) of the solution used for titration., V_0: The volume (mL) of sodium thiosulphate., and W: the weight (g) of the sample. To ensure precise results, each titration was carried out twice expressed as meq/kg butters.

2.5 Oil binding capacity

The oil binding capacity (OBC) of spread samples was investigated according to the method of Marra et al. (2023). About 1 g of sample was deposited into a microtube and centrifuged by benchtop centrifuge (1 – 15, Sigma, Germany) at 5000 rpm for 15 min and the content of the separated oil was calculated as follows:

$$\text{OBC}(\%) = \left(1 - \frac{M_0 - M}{M_0}\right) \times 100 \quad (2)$$

M_0: The initial mass of sample., and M: The mass of sample after centrifugation.

2.6 Spreadability analysis

The spreadability of the samples was evaluated using a TA Plus Texture Analyzer (Lloyd Instruments, England) equipped with a conical rig, comprising sample-containing female cones and a 90° male cone probe according toMarra et al. (2023). The spread samples placed in female cone, and the male cone probe was penetrated 22.5 mm into the sample at 1 mm/s. The spreadability firmness (N) was determined based on the maximum force needed to the most level of penetration, and the area under the curve was considered as the spreadability in which smaller area values reflected greater spreadability.

2.7 Texture analysis

The Texture Profile Analyzer TA Plus (Lloyd Instruments, England) was used to measure texture properties like hardness, adhesiveness, and cohesiveness. The samples were placed in a cylindrical plastic pot (43 mm height, 35 mm diameter) and prob penetrated twice the sample to a depth of 20 mm at 1 mm/s and returned. A 5-second recovery period was applied between the penetrations. This setup follows the methods by Golodnizky and Davidovich-Pinhas (2020) and Habibi et al. (2022). In the recorded curve, the maximum force obtained during the first compression cycle (or first bite), representing hardness in Newtons. In addition, the cohesiveness was determined by calculating the ratio of the area under the second compression curve to the area under the first compression curve during the second compression cycle. Adhesiveness was measured by calculating the area under the curve in the negative region.

2.8 Color analysis

A 500-d Series scanner (Minolta, Japan) (Cano Scan, LiDE 120 Scanner, Canon) was used to record the surface color of the SCs at a resolution of 600 dpi. The resulting images were converted from the RGB space to the LAB space using the plugin of the color-space converter in ImageJ software version 1.4. The color parameters measured were L*, a*, and b* (Ghorghi et al., 2023).

2.9 Sensory evaluation

2.9.1 Panel training

Quantitative Descriptive Analysis (QDA) was performed for the control and four SCs bigel samples based on walnut oil–rice bran wax oleogel and a guar gum hydrogel (Sarfarazi and Mohebbi, 2020; Yılmaz and Öğütcü, 2015). Ten trained assessors, aged 27 – 34 years, comprising five men and five women, were chosen for their sensory acuity, and ability to identify sensory attributes (Shakerardekani, 2017). The panel members underwented at least 2 hours of training to familiarize themselves with the sensory terms, definitions, and corresponding references listed in Table 2. A list of sensory descriptive terms was prepared based on the QDA tables that collected by Chu and Resurreccion (2005);

Table 2. Texture profile analysis and spreadability of chocolate spread samples containing different bigel ratio as a fat replacer (mean ± standard deviation).

Sample	Hardness (N)	Adhesiveness (N·mm)	Cohesiveness	Firmness (N)	Spread ability (N·mm)
SB1	$1.18 \pm 0.1^{d*}$	0.80 ± 0.05^{b}	0.65 ± 0.1^{ab}	9.06 ± 0.11^{e}	51.56 ± 0.07^{a}
SB2	1.82 ± 0.11^{c}	0.89 ± 0.1^{a}	0.52 ± 0.06^{b}	12.39 ± 0.08^{d}	45.20 ± 0.10^{b}
SB3	2.94 ± 0.1^{a}	0.71 ± 0.01^{c}	0.34 ± 0.04^{c}	19.04 ± 0.11^{a}	31.22 ± 1.33^{d}
SB4	2.37 ± 0.09^{b}	0.73 ± 0.01^{c}	0.22 ± 0.04^{c}	16.28 ± 0.14^{b}	37.91 ± 0.44^{c}
control	2.24 ± 0.14^{b}	0.92 ± 0.02^{a}	0.73 ± 0.01^{a}	14.03 ± 0.09^{c}	39.97 ± 1.20^{c}

* Different superscripts within each row indicate significant differences between mean values at ($p < 0.05$) according to the Duncan multiple range test.

Martínez-Cervera et al. (2011); Sarfarazi and Mohebbi (2020); Shakerardekani (2017); Yılmaz and Öğütcü (2015), and samples were given as standards with specific characteristics for each characteristic presented in the table. A line scale with a length of 10 cm was used to measure sensory attributesYılmaz and Öğütcü (2015).

2.9.2 Sample assessment

Before each test, 20 g of different spreads were placed in labeled containers with three-digit random codes (Shakerardekani, 2017; Yılmaz and Öğütcü, 2015). The study involved evaluating 15 chocolate spread samples in triplicate by having participants press the samples with their tongues (Brown et al., 2023; Shakerardekani, 2017). Above each line scale on the ballot, the name of the attribute to be rated and the assessors were asked to quantify each sensory attribute by marking a vertical line on a 10-cm unstructured scale to indicate the desired feature. Plain crackers were provided to assess the sample's spreadability (Shakerardekani, 2017). The relative intensity of the property was determined by measuring the distance between the low level and score using a ruler (Sarfarazi and Mohebbi, 2020).

2.9.3 Consumer test

The study assessed the overall acceptability of spreads regarding appearance, aroma, flavor, and spreadability, by 30 volunteers aged $18-45$ (15 males and 15 females) using 5-Point hedonic scale. Ten g of spread was presented with a three-digit number and were served together with slices of bread by each consumer. To determine their willingness to buy, they were given three options: buying, not buying, and maybe buying. Score sheets were collected and evaluated (Ghorghi et al., 2023; Yılmaz and Öğütcü, 2015).

2.10 Statistical analysis

One-way analysis of variance (ANOVA) was used to study the effect of bigel as a replacer on the textural or sensory characteristics of the spreads. The means were compared using Duncan's multiple range test (DMRT) at 95% confidence level with SAS software (9.1.3 Service Pack 4, SAS Institute Inc., Cary, NC, USA). The results were reported in mean $\pm$ standard deviation.

3. Results and discussion

3.1 Oxidative stability

Peroxide value (PV) indicates the primary oxidation of oil and the oxidation stability of its products during production and storage (Samui et al., 2021). The PV of the spread samples was assayed by controlling peroxide levels over 180 days (Fig. 1). In general, the PV of the SB4 and control samples reached 6.25 and 6.32 meq/kg after 180 days of storage. In contrast, replacing 50% of the palm oil with a bigel based on walnut oil–rice bran wax oleogel and a guar gum hydrogel reduced PV. Lower oxidation was observed in the SB1 and SB2 samples, which were significantly lower than those of the other samples ($P < 0.05$), associated with a decrease in total fat content. However, the PV values of all SBs were within the range allowed by international standards ($1-10$ meq/kg), which is accepted as the threshold for rancid oil (Park et al., 2018; Samui et al., 2021). It was expected that the PV of the SB1 and SB2 samples would increase and then decrease due to the high concentration of unsaturated fatty acids in walnut oil, which are susceptible to lipid oxidation (Cho et al., 2023). These results showed that using a bigel based on walnut oil, rice bran wax oleogel, and a guar gum hydrogel instead of palm oil had a positive preventive effect on oxidation in spread samples. In fact, the structured lipid in bigel could inhibit the migration of free radicals toward double bonds and the subsequent lipid oxidation. This finding is in agreement with Baltuonyte et al. (2022), Kim and Oh (2022), Lim et al. (2016), Cho et al. (2023). On the other hand, plant polysaccharide structures, such as guar gum, can scavenge free radicals and entrap water molecules, resulting in a limitation of reactive radical species' movement (Hamdani et al., 2018; Mumtaz Hamdani and Ahmed Wani, 2017; Cho et al., 2023). According to Quilaqueo et al. (2022) it was confirmed that gelling agents, used in sodium alginate and carboxymethylcellulose hydrogels, result in the increase of viscosity and enhance emulsion stability, while the final bigel contains lower fat content. It was found that palm oil has greater potential for oxidative reactions due to its higher fat content, suggesting a higher oxidation risk on the surface of spread samples (Peterson, 2013). Peterson (2013) reported that the addition of 5% water to lipid systems could react with polar peroxide molecules, prevent further oxidative reactions, lower free radicals, and result in a lower PV over time. Unlike the results obtained in this study, Siachou et al. (2023) reported that sausages formulated with bigels based on olive oil monoglycerides oleogel and gelatin, and κ-carrageenan, showed an increase in oxidation values, but within acceptable limits.

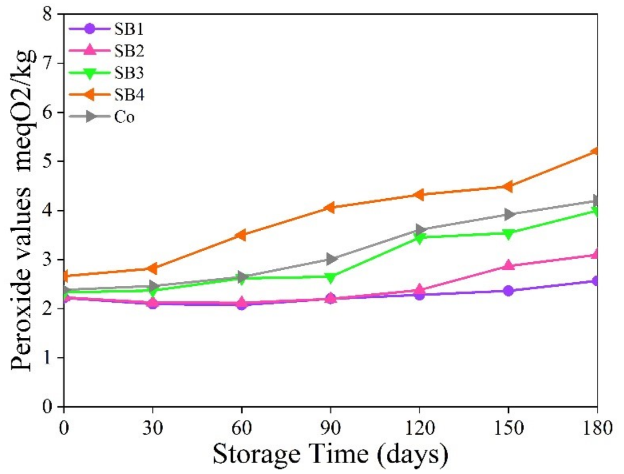

Figure 1. Trends in Peroxide values of chocolate spread samples containing bigel ratio as a fat replacer for 6 months.

3.2 Oil binding capacity (OBC)

The oil-binding capacity (OBC) is a crucial index for determining oil migration and investigating the stability during storage of fat-containing products (Marra et al., 2023; Vershkov and Davidovich-Pinhas, 2023). As shown in Table 3, the OBC of the spreadable chocolates was above 90%. The

Table 3. Color analysis and oil binding capacity (OBC) of chocolate spread samples containing different bigel ratio as a fat replacer (mean ± standard deviation).

Sample	L* value	a* value	b* value	OBC (%)
SB1	$23.34 \pm 0.01^{a*}$	15.14 ± 0.06^{a}	17.99 ± 0.14^{a}	99.91 ± 0.02^{a}
SB2	22.08 ± 0.01^{b}	14.69 ± 0.03^{b}	17.10 ± 0.15^{b}	99.89 ± 0.04^{a}
SB3	21.87 ± 0.01^{c}	11.59 ± 0.06^{c}	17.83 ± 0.07^{a}	99.82 ± 0.09^{a}
SB4	21.34 ± 0.01^{d}	11.38 ± 0.07^{c}	9.49 ± 0.07^{c}	98.45 ± 0.65^{b}
control	21.26 ± 0.02^{e}	11.36 ± 0.06^{c}	9.43 ± 0.07^{c}	96.12 ± 0.14^{c}

* Different superscripts within each row indicate significant differences between mean values at (p ¡ 0.05) according to the Duncan multiple range test.

OBC of SB1 and SB2 proved the effect of bigel as a fat replacer on the OBC of the samples. The obtained results indicated that the strong gel properties of bigel result in a perceptible impact on the OBC of the SB. he spread samples (SB1 and SB2) containing 100% and 75% replacement of palm oil with bigel showed the highest OBC values of 99.91% and 99.89% respectively; also, the control spread sample containing 100% palm oil had the lowest OBC of 96.12%. Oba and Yıldırım (2024) reported that the oil-binding capacity of chocolate spreads prepared with bigels increased with higher bigel concentration, showing OBC values ranging from 92.73% to 99.54%. Obviously, replacing bigel in the spread formulation resulted in greater oil retention in the spread samples. These findings highlighted the desired oil-retention potential of bigel-based chocolate spread, along with improved physical stability during storage.

3.3 Texture

Texture is considered an essential feature of spread associated with sensory attributes during consumption (Ghorghi et al., 2023). The results of the hardness, adhesiveness, and cohesiveness analysis of the samples are given in Table 2. As shown, the hardness of SB3 and SB4 was 2.94 and 2.37 N, respectively, and was significantly higher than that of the CO sample, which could be due to poor emulsification between palm oil and bigel. Replacing 100% of the palm oil with bigel in the SB1 sample resulted in significantly lower hardness than in the other samples ($P < 0.05$). Oba and Yıldırım (2024) reported that the control sample exhibited higher hardness than chocolate spreads prepared with bigels, which may be attributed to its lower moisture or oil content and indicates greater stability.

The adhesiveness of SB4 and SB3 was significantly lower than that of the CO sample, whereas SB1 and SB2 had the highest adhesiveness ($P < 0.05$). The decrease in fat content (palm oil) and the increase in bigel ratio increased the adhesiveness of the spread texture. The adhesiveness of SB2 was comparable to that of the CO sample, which was more suitable for use as a spread. The network structure of bigel and the interaction between fat and bigel are in favor of the adhesion of bigel-based spread samples. Unlike our result, Li et al. (2024) found that the adhesiveness of bigels based on a walnut oil oleogel and a chitosan hydrogel was significantly lower than that of commercial spreads, which was attributed to an increase in the Candelilla wax/span 65 oleogel proportion in the bigel.

Cohesiveness is the tendency of a product to cohere or stick together. It describes how well a food maintains its form between the 1st and 2nd chews, which is directly related to its tensile and compressive strength. This feature of spread is involved in having desired spreadability on surfaces, such as bread (2019). In general, the cohesiveness of the SB3 and SB4 samples was significantly higher than that of the other samples ($P < 0.05$). Based on the result, it is clear that the incorporation of bigel into palm oil (75:25) influenced the cohesiveness of the spread samples. These results indicated that SB2 with a glossy surface is more accepted by consumers as a spreadable chocolate. Li et al. (2024) indicated that higher cohesiveness results in the formation of impact spread, which is beneficial for packaging and storage practices.

3.4 Spreadability

Spreadability is an essential physical characteristic of spreads to sensory acceptance by consumers (Tirgarian et al., 2023). Small, uniform fat crystals lead to a smooth, soft texture, with oil well retained within the matrix. In fact, spreadability can be considered an indirect indicator of fat system stability; products that spread easily and uniformly typically exhibit minimal oil separation. The hardness and spreadability of the spreadable chocolates containing different bigel ratios are reported in Table 2. The results showed that SB1 had lower hardness and spreadability than other SBs ($p < 0.05$), and its texture was 1.5 times softer than that of palm oil spreadable chocolate. found that hazelnut-based spreads had lower hardness and spreadability when the palm oil ratio was decreased. As observed, the SB2 sample had firmness similar to that of the palm oil samples, with a higher spreadability value. (Oba and Yıldırım, 2024) showed that an increased proportion of bigel in chocolate spread enhanced spreadability, likely due to a reduction in saturated fat from palm oil and a corresponding increase in unsaturated fat content. Replacing 75% of the bigel in the produced chocolate spread (SB2) resulted in a more complex texture ($p < 0.05$) compared with SB1. Tirgarian et al. (2023) reported that as aw increased in the sample, the water-to-corn oil-glycerol monostearate oleogel ratio (55:45), the firmness, and spreadability of chocolates decreased due to the softening effect of free water. In Glibowski et al. (2008) study, samples containing lower fat showed better spreadability. However, the content of solids, the polymorphic indices, and the crystal dimensions have influenced the hardness. As shown in Table 1, SB3 and SB4 had the highest hardness and stiffer texture with lower spreadability. Generally, the amount of solid fat has a key role in the firmness of spreads (Fayaz et al., 2017). Therefore, our result is expected regarding the solid fat content of the spread samples. Previous studies have shown that bigel-based doughs, composed of an alginate/k-carrageenan hydrogel and a rice bran wax/soybean oil oleogel, have firmness that increases with higher solid fat content, resulting in greater rigidity (Nutter et al., 2023). These findings could be considered to discuss the highest and lowest firmness and spreadability in the SB3 and SB1 samples.

3.5 Color

Color is a physical parameter and crucial for quality control in products like chocolate spread (Fig. 2). The results of color analysis are given in Table 3, including L* (lightness), a* (The position between red and green), and b* (The position between yellow and blue) values. The L* of the analyzed samples was low, ranging from 21.26 to 23.34, which is typically expected for a dark chocolate spread. The L* or lightness followed a descending trend in spread samples as the bigel ratio decreased in the spread formulation. Regarding bigel, which had a light yellowish, creamy appearance, increasing its substitution in SB1 and SB2 led to a higher brightness value. The obtained results for a* and b* of samples contributing to the "brown" color, which is a combination of red (+a*) and yellow (+b*). Besides, these results prove that the products made from chocolate (Salama and Hashim, 2022; Oba and Yıldırım, 2024). The spread samples containing the highest level of bigel (SB1, SB2) presented the highest a* values (15.14 and 14.69, respectively) ($p < 0.05$), which indicates a potential to red color, as reported by Tirgarian et al. (2023). Oba and Yıldırım (2024) reported that replacing palm oil with hydrogel due to increased beeswax and carnauba wax content led to an increase in the a* and b* values. Tirgarian et al. (2023), Oba and Yıldırım (2024) reported that higher light and smooth appearance affected consumer acceptance. Generally, Oba and Yıldırım (2024) stated that hydrogel/oleogel containing plant oil changed the lightness of spreads, as wheat oil resulted in the highest brightness, and the lowest brightness was observed in pistachio oil. Tirgarian et al. (2023) found that replacing water with corn oil- glycerol monostearate oleogel in water-in-oleogel emulsions led to a lighter color in spread chocolate. Therefore, increasing the percentage of bigel, which is accompanied by a higher proportion of hydrogel in the product, leads to increased color intensity and brightness.

3.6 Sensory evaluation

Sensory evaluation is crucial for understanding how fat variation impacts the perception of chocolate spread. A trained panel conducted a test evaluating five samples of chocolate spread using Sensory Quantitative Descriptive Analysis (QDA). The obtained data are summarized in Table 4. In this regard, some descriptive indices (Table 2) used by the panel to evaluate the prepared chocolate spread include appearance (Oiliness, Smoothness, color), texture (Hardness, Adhesiveness, Spreadability), taste (Chocolate taste), and mouth-feeling properties (Mouth coating). According to the results, all sensory characteristics changed significantly with changes in bigel content, indicating that the incorpora-

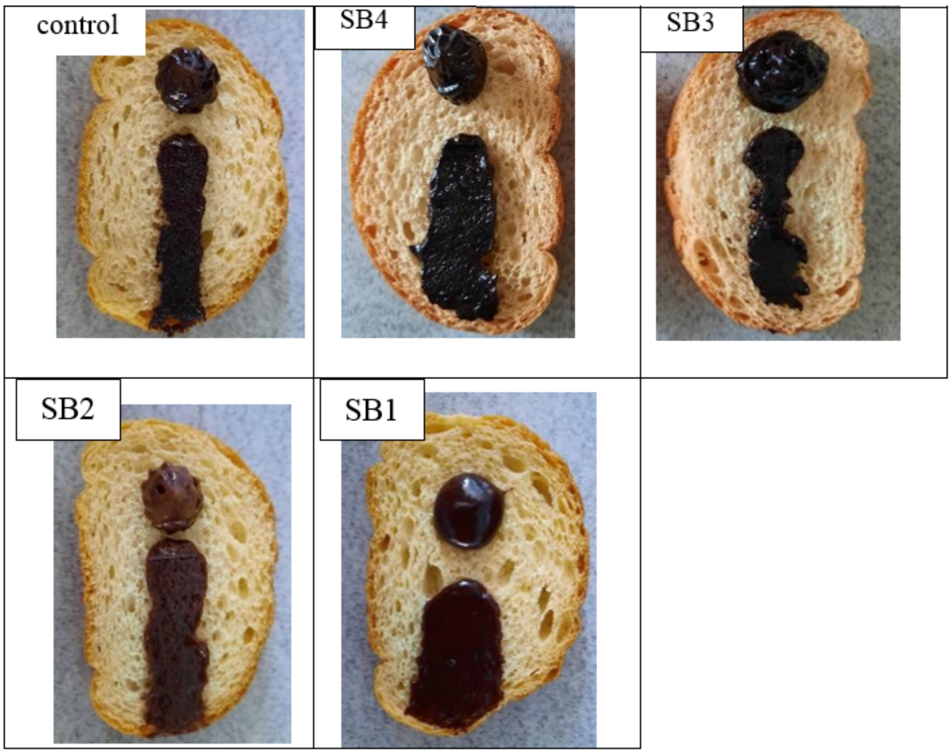

Figure 2. Spreadability of chocolate spread samples containing bigel ratio as a fat replacer.

Table 4. List of sensory descriptive terms, definitions, and evaluation methods used in the quantitative descriptive analysis of chocolate spread samples containing bigel ratio as a fat replacer.

Attributes		Definition	Assessment method (min 0: max 10)
Appearance		Take off lid from the cup and look at the sample	
	Brown color	Typical chocolate color intensity in the spread	Chocolate Mousse– Chocolate syrup
	oiliness	The amount of oiliness on the surface	Mayonnaise–Walnut oil
	Glossy	Degree of surface reflectance of light from the product	Marshmallows–Glazed Donuts
Manual texture		Cut and spread 5 g of sample on a piece of toast bread by a knife.	
	Hardness	Force required to push a knife into sample	Mayonnaise – Peanut butter
	spreadability	The simplicity of spreading the sample thinly over a surface	Peanut butter – Mayonnaise
Oral texture		Place 1/4 tsp of a sample in the mouth and evaluate for feeling factor	
	Adhesiveness	Force required to remove sample adhered to the roof of the mouth using the tongue	Mayonnaise – Peanut butter
	Smoothness	Lack of surface particles between the tongue and the palate	Peanut butter– Chocolate syrup
	Mouth coating	Perception of a fatty layer in the mouth (on the teeth and upper jaw)	Full fat milk–Peanut butter
	Creaminess	Perception of a soft and comprehensive feeling	Skim milk – Cream
Flavor	Chocolate taste	Typical strength of chocolate taste	60% Dark Chocolate - Chocolate Mousse

tion of bigel affected product sensory perception (Fig. 3). Color affects the panel members' acceptance decisions. The panelists generally liked the color of the chocolate spread containing high bigel; it might be related to the dark chocolate color rather than the control spread chocolate. The highest color rating was for the SB2 and SB1 Samples at 9.6 cm and 9.1 cm, respectively. The intensity of brown color can be attributed to the dissolution of pigments such as flavonoids and tannins of Cocoa powder within the hydrogel phase, resulting in a stronger chocolate color in the sample. Tirgarian et al. (2023) reported that color and brightness attributes increased in chocolate spreads as the fat content decreased. In Pourfarzad and Derakhshan (2021) study, the incorporation of hydrocolloids improves the visual characteristics of hazelnut sauce. Moreover, the score for spread oiliness decreased with increasing the bigel ratio, with the control sample having the most significant impact on surface oiliness evaluation. The use of walnut oil in the bigel structure creates an oily feeling among panelists. Analogous to the previous attributes, the samples SB1 and SB2 received high smoothness scores (Table 3). The addition of bigel, a novel structured fat system (Quilaqueo et al., 2022), has been shown to cause smoother surfaces, creaminess, and a glossy appearance, which are attributed to gelling agents. These gelling agents can also be used as fat substitutes. The creamy mouthfeel is achieved by increasing in-mouth coalescence of fat droplets. Besides, the fat melting in the oral cavity results in a better mouthfeel. On the other hand, polysaccharides play a significant role in the creamy mouthfeel of low-fat products as they maintain higher softness and creaminess.

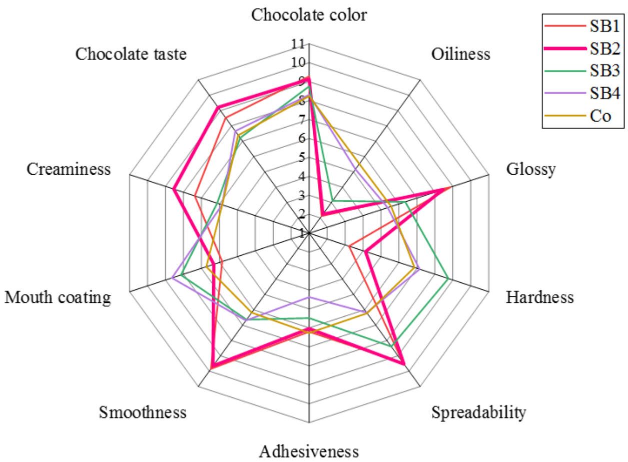

Figure 3. Radar chart of the sensory attributes of chocolate spread samples.

Regarding hardness, the lowest and highest hardness scores were observed in SB1 (100% bigel) and SB4 (25% bigel), respectively (Table 3). With increasing bigel incorporation in the spreadable chocolate, the trend in hardness decreased. This sensory finding is according to the sensory analysis results (Table 1).

Adhesiveness refers to the force required to remove stickiness from the mouth during eating (Sanders et al., 2014). As shown in Table 4, substituting palm oil with bigel increased the adhesiveness of the spreadable chocolate, likely due to the higher surface area of the gel structure used, which allows greater interaction between the materials (Abdullah Liu et al., 2022). Likewise, the higher adhesiveness of SB2 (6.27) can be attributed to its lower palm oil content. Additionally, gels can form a network structure that traps other materials, such as water, within the product, thereby increasing adhesion and soft texture (Chandra and Shamasundar, 2015). The sensory attributes of the chocolate spread were determined by spreading a quantity of each sample onto toast with a knife. The ratings of spreadability across different bigel ratios were SB1 > SB2 ≥ Co > SB3 ≥ SB4, consistent with the instrumental spreadability parameter (Table 1).

The assessors distinguished between the taste and aftertaste of chocolate, which increased as bigel content increased. The taste is determined by the main ingredients, such as sugar and cocoa powder, distributed throughout the final spread structure. However, this phenomenon has been reported in similar studies. In SB3 and SB4 samples, an increase in the fat phase led to a more distinct melting profile and a lower chocolate aftertaste. Brown et al. (2023) also reported that higher fat content was associated with higher bitterness and lower coca odor (Brown et al., 2023). Mouth coating is an unwanted attribute in chocolate spread and is defined as the deposition of a thin layer of fat on the palate (Zhou et al., 2022). As illustrated in Table 3, there is a significant difference among spreads containing different bigel ratios. In the 25% and 50% Bigel ratios, the ratings for mouth coating were increased, which could be owing to the simultaneous presence of wax oleogels in Bigel, which strengthened their effects. In SB3, bigel substitution increased the sample's solid fat content, melting points, and mouthfeel. These findings are in line with the study by Zhou et al. (2022), who observed that higher solid fat content evokes fat-based perception. Similar results have also been observed in reduced-fat chocolate spreads, in which greater water incorporation led to a lower mouth-coating sensation (Yılmaz and Öğütcü, 2015). Furthermore, the emulsion's oral smoothness and mouth-coating attributes were most strongly correlated with overall creaminess perception Zhou et al. (2022).

3.7 Consumer test

The results of the acceptance test of the chocolate spreads developed by bigel, compared with the control sample using a hedonic test, are illustrated in Fig. 4. As shown, the appearance, flavor, spreadability, and overall acceptance of the SB2 sample were higher than 3.5, indicating higher acceptance than average (2.5) moreover, since color affected the appearance of the product and consumers' acceptance. The observed differences in the color samples indicate that 75% replacement enhanced the appearance indexes. These results are consistent with the color measurements. We found that the spreadability of samples containing 25% and 75% fat replacement had the lowest and highest acceptability, respectively. The obtained spreadability score of > 4.0 for SB2 indicates high acceptance. Yılmaz and Öğütcü (2015) also found that the chocolate spread samples based on bigel had higher spreadability scores than the control one. Flavor characterizes the sweetness and bitterness, as well as the product's smell. The flavor scores of the SB2 were higher than those of the SB3 and SB4 ($p < 0.05$), and had stronger, more intense flavor than the control sample, confirming the finding from the QDA analysis (Table 5). The lowest flavor acceptance was observed for SB4 (2.39), and the highest and lowest overall acceptance scores were for SB2 and SB4, respectively. It means that consumers discriminated against chocolate spreads that were slightly disliked

Table 5. Quantitative descriptive analysis evaluation scores of spreadable chocolates prepared with increasing quantities of bigel as a fat replacer.

Samples	Chocolate color	Oiliness	Glossy	Hardness	Spreadability	Adhesiveness	Smoothness	Mouth coating	Creaminess	Chocolate taste
SB1	8.53 ± 1.16^{a}	2.19 ± 1.09^{d}	9.04 ± 1.18^{a}	3.19 ± 1.05^{e}	9.36 ± 1.70^{b}	6.20 ± 1.05^{a}	9.66 ± 1.42^{a}	5.85 ± 1.14^{c}	7.50 ± 1.32^{b}	8.68 ± 1.16^{b}
SB2	8.22 ± 1.10^{b}	2.21 ± 1.74^{d}	8.88 ± 1.13^{b}	4.16 ± 1.05^{d}	9.78 ± 1.48^{a}	6.27 ± 1.31^{a}	9.68 ± 1.11^{a}	5.8 ± 1.33^{c}	8.62 ± 1.25^{a}	9.28 ± 1.13^{a}
SB3	7.72 ± 1.08^{c}	3.27 ± 1.17^{c}	5.49 ± 0.2^{d}	8.72 ± 1.10^{a}	5.36 ± 1.26^{e}	5.48 ± 1.18^{b}	5.82 ± 1.29^{c}	8.28 ± 1.94^{a}	5.73 ± 1.16^{c}	7.27 ± 1.08^{d}
SB4	7.39 ± 0.11^{d}	5.32 ± 1.35^{b}	5.22 ± 1.12^{e}	7.19 ± 1.44^{b}	5.75 ± 1.51^{d}	4.37 ± 1.80^{c}	5.97 ± 0.55^{c}	8.48 ± 1.39^{a}	5.66 ± 1.16^{c}	7.71 ± 1.99^{c}
Control	7.19 ± 1.10^{d}	5.57 ± 1.86^{a}	6.32 ± 0.88^{c}	6.95 ± 0.18^{c}	6.00 ± 1.16^{c}	6.04 ± 1.18^{a}	6.27 ± 0.97^{b}	7.41 ± 1.26^{b}	5.87 ± 1.19^{c}	7.74 ± 1.52^{c}

* Different superscripts within each row indicate significant differences between mean values at ($p < 0.05$) according to the Duncan multiple range test ($n = 3$).

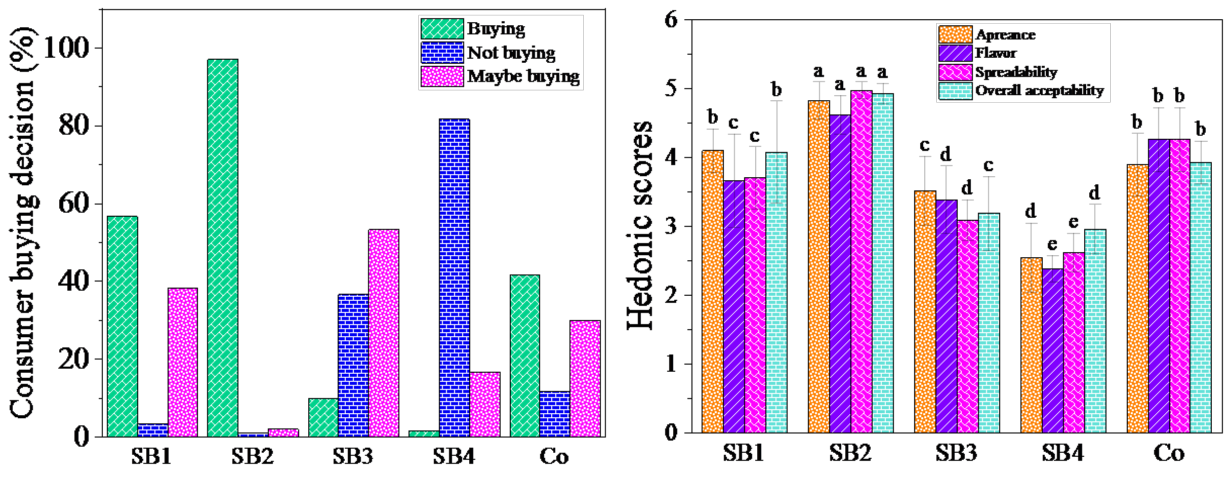

Figure 4. Results of Hedonic scores of acceptability test (a), and consumer buying decision (b) of chocolate spreads ($n = 60$).

(SB4) and those that were liked very much (SB2). This study revealed that replacing palm oil with bigel at 75% significantly enhanced acceptance (Fig. 4).

In the completed consumer test, consumers reported that they tend to buy developed spread products (Fig. 4). Approximately 97% of the consumers stated that they certainly buy SB2. At the same time, the percentages for SB1, SB3, SB4, and CO were 56.67%, 10%, 1.66%, and 41.67%, respectively. This was consistent with the overall acceptability scores (Fig. 4). The buying decision data indicate that consumers usually accept and would buy, especially the SB2 samples. In this study, the consumers were not provided with any knowledge about the samples.

4. Conclusion

Incorporating walnut oil–based bigel as a fat replacer in chocolate spread resulted in a stable product with a higher unsaturated fat content. Replacing palm oil with bigel decreased hardness and increased spreadability in SB1 and SB2. A 75% substitution with bigel led to improvements in quality parameters and yielded a structure comparable to that of the control samples. Furthermore, 100% replacement formed higher-homogeneous spreads with very smooth textures that can be associated with bigel structure. Taken together, the use of bigel enhanced the technological properties of the chocolate spread, including its nutritional value, while reducing its fat content. From a sensory perspective, the spreads with 75% bigel were rated as more acceptable. They showed sensory evaluations similar to the control spread in terms of acceptance of creamy texture and flavor. Consequently, the hydrogel/oleogel structure of the developed bigel can be recommended as a safe alternative for incorporating into chocolate spread formulation.

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Authors contributions

All authors contributed equally to the conception, design, execution, and writing of this work. All authors read and approved the final manuscript.

Availability of data and materials

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interests

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.

References

Abdullah Liu L., Javed H. U., Xiao J. (2022) Engineering Emulsion Gels as Functional Colloids Emphasizing Food Applications: A Review. *Frontiers in Nutrition* 9

Acan B. G., Kilicli M., Bursa K., Toker O. S., Palabiyik I., Gulcu M., Yaman M., Gunes R., Konar N. (2022) Effect of grape pomace usage in chocolate spread formulation on textural, rheological and digestibility properties. *LWT* 138:110451.

Almeida P. F. D., Lannes S. (2017) Effects of chicken by-product gelatin on the physicochemical properties and texture of chocolate spread. *Journal of Texture Studies* 48 (2): 392–402.

Baltuonyte G., Eisinaite V., Kazernaviciute R., Vinauskiene R., Jasutiene I., Leskauskaite D. (2022) Novel Formulation of Bigel-Based Vegetable Oil Spreads Enriched with Lingonberry Pomace. *Foods* 11:2213.

Banas K., Piwowar A., Harasym J. (2024) Agar-rapeseed oil hydroleogels as solid fat substitute in short-bread cookies. *Food Hydrocolloids* 151:109889.

Brown A. L., Warren E. R., Ingrraham B. W., Ziegler G. R., Hopfer H. (2023) The effect of fat content on sensory perception and consumer acceptability of 70% cacao dark chocolate made from reconstituted cocoa liquor. *Journal of Sensory Studies* 36:e12864.

Chandra M. V., Shamasundar B. A. (2015) Texture Profile Analysis and Functional Properties of Gelatin from the Skin of Three Species of Fresh Water Fish. *International Journal of Food Properties* 18:572–584.

Chao E., Li J., Duan Z., Fan L. (2024) Bigels as emerging biphasic systems: Properties, applications, and prospects in the food industry. *Food Hydrocolloids* 154:110089.

Cho K., Tarte R., Acevedo N. C. (2023) Development and characterization of the freeze-thaw and oxidative stability of edible rice bran wax-gelatin biphasic gels. *LWT* 174:114330.

Chu C. A., Resurreccion A. V. A. (2005) Sensory profiling and characterization of chocolate peanut spread using response surface methodology. *Journal of Sensory Studies* 20:243–274.

Cui H., Tang C., Wu S., Julian Mcclements D., Liu S., Li B., Li Y. (2022) Fabrication of chitosan-cinnamaldehyde-glycerol monolaurate bigels with dual gelling effects and application as cream analogs. *Food Chemistry* 384:132589.

Espert M., Wiking L., Salvador A., Sanz T. (2020) Reduced-fat spreads based on anhydrous milk fat and cellulose ethers. *Food Hydrocolloids* 99:105330.

Fayaz G., Goli S. A. H., Kadivar M., Valoppi F., Barba L., Calligaris S., Nicoli M. C. (2017) Potential application of pomegranate seed oil oleogels based on monoglycerides, beeswax and propolis wax as partial substitutes of palm oil in functional chocolate spread. *LWT* 86:523–529.

Fernandes Almeida R., Aguiar Borges L., Silva T. Torres da, Santos N. Serafim Timotea dos, Gianasi F., Augusto Caldas Batista E., Efraim P. (2024) Chocolates, compounds and spreads: A review on the use of oleogels, hydrogels and hybrid gels to reduce saturated fat content. *Food Res Int* 178:113986.

Francavilla A., Corradini M. G., Joye I. J. (2023) Bigels as Delivery Systems: Potential Uses and Applicability in Food. *Gels* 9:648.

Ghorghi Z. B., Yeganehzad S., Hesarinejad M. A., Faezian A., Kutsenkova V., Gao Z., Nishinari K., Nepovinnykh N. (2023) Fabrication of novel hybrid gel based on beeswax oleogel: Application in the compound chocolate formulation. Food Hydrocolloids:108599.

Glibowski P., Zaraycki P., Krzpkowska M. (2008) The Rheological and Instrumental Textural Properties of Selected Table Fats. *International Journal of Food Properties* 11:678–686.

Golodnizky D., Davidovich-Pinhas M. (2020) The Effect of the HLB Value of Sucrose Ester on Physiochemical Properties of Bigel Systems. *Foods* 9:1857.

Habibi A., Kasapis S., Truong T. (2022) Effect of hydrogel particle size embedded into oleogels on the physico-functional properties of hydrogel-in-oleogel (bigels). *Lwt-Food Science and Technology,* 163.

Hamdani A. M., Wani I. A., Bhat N. A., Siddiqi R. A. (2018) Effect of guar gum conjugation on functional, antioxidant and antimicrobial activity of egg white lysozyme. *Food Chemistry* 240:1201–1209.

Kim D., Oh I. (2022) The Characteristic of Insect Oil for a Potential Component of Oleogel and Its Application as a Solid Fat Replacer in Cookies. *Gels* 8:355.

Li C., Xu Y., Zhang Y., Shen Y., Deng X., Wang F. (2024) Novel bigels based on walnut oil oleogel and chitosan hydrogel: Preparation, characterization, and application as food spread. *International Journal of Biological Macromolecules* 260:129530.

Lim J., Hwang H.-S., Lee S. (2016) Oil-structuring characterization of natural waxes in canola oil oleogels: rheological, thermal, and oxidative properties. *Applied Biological Chemistry*

Manzocco L., Calligaris S., Camerin M., Pizzale L., Nicoli M. C. (2014) Prediction of firmness and physical stability of low-fat chocolate spreads. *Journal of Food Engineering* 126:120–125.

Marra F., Lavorgna A., Incarnato L., Malvano F., Albanese D. (2023) Optimization of Hazelnut Spread Based on Total or Partial Substitution of Palm Oil. *Foods* 12:3122.

Martins A. J., Silva P., Maciel F., Pastrana L. M., Cunha R. L., Cerqueira M. A., Vicente A. A. (2019) Hybrid gels: Influence of oleogel/hydrogel ratio on rheological and textural properties. *Food Research International* 116:1298–1305.

Martínez-Cervera S., Salvado A., Muguerza B., Moulay L., Fiszman S. M. (2011) Cocoa fibre and its application as a fat replacer in chocolate muffins. *LWT - Food Science and Technology* 44:729–736.

Mumtaz Hamdani A., Ahmed Wani I. (2017) Guar and Locust bean gum: Composition, total phenolic content, antioxidant and antinutritional characterisation. *Bioactive Carbohydrates and Dietary Fibre* 11:53–59.

Nutter J., Shi X., Lamsal B., Acevedo N. C. (2023) Plant-based bigels as a novel alternative to commercial solid fats in short dough products: Textural and structural properties of short dough and shortbread. *Food Bioscience* 54:102865.

Oba S., Yıldırım T. (2024) Using plant-based hydrogel-oleogels to replace palm oil: impact on texture, sensory, and fatty acid composition of chocolate spreads. *Journal of Food Measurement and Characterization* 18:8931–8943.

Park C., Bemer H. L., Maleky F. (2018) Oxidative Stability of Rice Bran Wax Oleogels and an Oleogel Cream Cheese Product. *Journal of the American Oil Chemists' Society* 95:1267–1275.

Peterson H. J. (2013) The effect of cocoa powder on the development of oxidative rancidity in peanut products.

Pourfarzad A., Derakhshan N. (2021) Effect of xanthan, guar and tragacanth on quality and shelf life of hazelnut sauce: study with generalized regression, PCA and PLSR techniques. *Journal of Food Measurement and Characterization* 15:1–13.

Puscas A., Chende A. (2020) Cocoa spreadable products based on flax seed oil organogels – textural characterization and proposed production technology.

Quilaqueo M., Iturra N., Contardo I., Millao S., Morales E., Rubilar M. (2022) Food-Grade Bigels with Potential to Replace Saturated and Trans Fats in Cookies. *Gels* 8:445.

Saffold M., Acevedo M. (2021) Development of Novel Rice Bran Wax/Gelatin-Based Biphasic Edible Gels and Characterization of their Microstructural, Thermal, and Mechanical Properties. *Food and Bioprocess Technology* 14:2219–2230.

Salama H. H., Hashim A. F. (2022) A functional spreadable canola and milk proteins oleogels as a healthy system for candy gummies. *Scientific Reports* 12:12619.

Samui T., Golddenisky D., Rosen-Kligvasser J., Davidovich-Pinhas M. (2021) The development and characterization of novel in-situ bigel formulation. *Food Hydrocolloids* 113

Sanders C. T., Demasie C. L., Kerr W. L., Hargrove J. L., Pegg R. B., Swanson R. B. (2014) Peanut skins-fortified peanut butters: Effects on consumer acceptability and quality characteristics. *LWT - Food Science and Technology* 59:222–228.

Sarfarazi M., Mohebbi M. (2020) An investigation into the crystalline structure, and the rheological, thermal, textural and sensory properties of sugar-free milk chocolate: effect of inulin and maltodextrin. *Journal of Food Measurement and Characterization* 14:1568–1581.

Shakerardekani A. (2017) Consumer Acceptance and Quantitative Descriptive Analysis of Pistachio Spread. *Journal of Agricultural Science and Technology* 19:85–95.

Shakouri S., Arabshahi S., Madanchi H., Mohammadifar M. A., Abdolshahi A. (2024a) Effect of carboxymethyl cellulose incorporation to gelatin-sunflower oil bigel on the physicochemical and structural properties. *Polymers for Advanced Technologies* 35:e6567.

Shakouri S., Tehrani M. M., Koocheki A., Farhoosh R., Abdolshahi A., Shariatifar N. (2024b) Bigels as Novel Drug Delivery Systems: A Systematic Review on Efficiency and Influential Factors. *Current Reviews in Clinical and Experimental Pharmacology.*

Siachou C., Zampouni K., Katsanidis E. (2023) Bigels as Fat Replacers in Fermented Sausages: Physicochemical, Microbiological, Sensory, and Nutritional Characteristics. *Gels* 9:340.

Silva P. M., Cerqueira M. A., Martins A. J., Fasolin L. H., Cunha R. L., Vicente A. A. (2022) Oleogels and bigels as alternatives to saturated fats: A review on their application by the food industry. *Journal of the American Oil Chemists' Society* 99:911–923.

Silva R. C. D., Ferdaus M. J., Foguel A., Da Silva T. L. T. (2023) Oleogels as a Fat Substitute in Food: A Current Review. *Gels* 9:180.

Singh V. K., Banerjee I., Agarwal T., Pramanik K., Bhattacharya M. K., Pal K. (2014) Guar gum and sesame oil based novel bigels for controlled drug delivery. *Colloids Surf B Biointerfaces* 123:582–92.

Skelhon T. S., Olsson P. K., Morgan A. R., Bon S. A. (2013) High internal phase agar hydrogel dispersions in cocoa butter and chocolate as a route towards reducing fat content. *Food Funct* 4:1314–21.

Tirgarian B., Yadegari H., Bagheri A., Neshagaran E., Mardani M., Farmani J. (2023) Reduced-fat chocolate spreads developed by water-in-oleogel emulsions. *Journal of Food Engineering* 337:111233.

Trapp L., Kafashian S., Schacht H., Nirschl H., Guthausen G. (2024) Quality control of hazelnut-based spreads: 1H TD-NMR transverse relaxation. *Frontiers in Food Science and Technology*

Vershkov B., Davidovich-Pinhas M. (2023) The effect of preparation temperature and composition on bigel performance as fat replacers. *Food & Function* 14:3838–3848.

Yılmaz E., Öğütcü M. (2015) Oleogels as spreadable fat and butter alternatives: sensory description and consumer perception. *RSC Advances* 5:50259–50267.

Zhou H., Zhao Y., Fan D., Shen Q., Liu C., Luo J. (2022) Effect of Solid Fat Content in Fat Droplets on Creamy Mouthfeel of Acid Milk Gels. *Foods* 11