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Development and Quality Evaluation of Oleogels from Soybean Oil and Beeswax Blends

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Abstract

Beeswax can structure soybean oil into oleogels for potential food applications. This study developed soybean oil–beeswax oleogels and evaluated the influence of beeswax concentration on their textural, instrumental color, and physicochemical properties. Beeswax replaced 5%, 10%, and 15% of the soybean oil, and the blends were heated at 106 °C to form oleogels. The resulting formulations were characterized using standard analytical methods. Beeswax incorporation improved textural characteristics and altered instrumental color. Increasing beeswax concentration decreased lightness (L*) from 46.43 to 40.52, while increasing total color difference (ΔE) from 4.28 to 8.65 and chroma difference (ΔC) from 18.96 to 42.36. Across the formulations, pH ranged from 5.80 to 6.35, peroxide values from 25.00 to 64.00 meq/kg, p-anisidine values from 1.45 to 3.15, and total oxidation (TOTOX) values from 53.15 to 129.45. These findings demonstrate that beeswax concentration influences the textural, color, and physicochemical characteristics of soybean oil oleogels. The formulation containing 15% beeswax exhibited the most favorable overall characteristics, supporting its consideration for potential bakery applications.

Keywords: Soybean Oil; Beeswax; Oleogelation; Physicochemical Properties; Oxidative Stability

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INTRODUCTION

Solid fats such as margarine, butter etc play pivotal role in achieving the desired textural and sensory characteristics in various food products. They give the desired crumb structure and mouthfeel in baked foods (Blake and Marangoni, 2015). However, high consumption of solid fats, which are rich in saturated fatty acids (SFAs) and trans fatty acids (TFAs), has been associated with elevated risk of various health issues, including obesity, coronary heart disease, cancer, diabetes, and allergies (Liu *et al*., 2017). In this regard, a number of potential fat replacers have been developed and used to reduce fat content in food matrices while maintaining the sensory properties that are usually attributed to dietary fat (Abdel- Moemin *et al*., 2018). These fat replacers are sub-categorised as either fat substitutes or fat mimetics. Fat substitutes replicate the functional and sensory properties of fat in food, usually contain no energy or less energy than fat, and may be used to replace some or all of the fat normally present in a product (Colla *et al*., 2018). Fat mimetics are protein- or carbohydrate-based ingredients that are not used to fully substitute the use of fat, but rather replicate some of the properties that fat provides within a food (Abdel- Moemin *et al*., 2018). Based on this classification many baked products on the market currently utilize fat replacers to reduce the total energy or fat content while maintaining consumer acceptance. Nutrition experts recommend replacing saturated and trans fats with healthy fat alternatives such as liquid vegetable oils due to health negative impact of saturated and trans fats (Dominguez *et al*., 2024). However, the replacement of solid fats with liquid vegetable oils in some food formulations results in technological problems such as oil migration during storage and negative impacts on texture and other sensory properties of the final product (Hooper *et al*., 2015). Additionally, unsaturated vegetable oils have lower oxidative stability than that of solid fats, resulting in food with shorter shelf life. Therefore, efforts are made to find solid fat-alternatives or fat-replacers with functional properties and mouthfeel like those of saturated fats and without adverse health impacts (Dominguez *et al*., 2024). The use of oleogels is one of the efforts made in this regard.

Oleogels are restructured semi-solid lipids prepared by transforming liquid vegetable oils into gels without chemical modifications. Oleogels are prepared by dispersing small amount of structuring agents (oleogelators) into liquid vegetable oils, which turns them into a gel-like phase (Dassanayake *et al*., 2011). Oleogels are prepared by direct dispersion of hydrophobic oleogelators such as fatty acids, waxes, and monoglycerides into

oils under heating and stirring conditions to fully dissolve oleogelators, followed by cooling to induce nucleation and crystal growth, leading to the formation of self- assembled networks (Dassanayake *et al.*, 2011). Other indirect approaches such as emulsion-templated methods have also been applied in the preparation of hydrophilic polymers-based oleogels (Pinto *et al.*, 2021). Formation of structural framework in an aqueous solvent or water continuous emulsion is required in the indirect methods. Oleogels offer a promising solution by enabling the replacement of unhealthy fats without compromising the texture, mouthfeel, or functionality of the final product (Ferdaus *et al.*, 2024). In recent years, oleogels gained attention to developing food products that meet health guidelines and the growing consumer demand for low-fat options (Dassanayake *et al.*, 2011). Additionally, oleogels have emerged as effective carriers for bioactive compounds, as they can entrap and stabilize these health-promoting substances within a structured lipid matrix. Consequently, they prevent the degradation of bioactive compounds during food processing, storage, and particularly in digestion (Pinto *et al.*, 2021). Oleogelation, a novel technology for structuring liquid oils into semi-solid systems using organogelators such as beeswax, has emerged as a promising solution. However, the development of oleogels that mimic the functionality of conventional solid fats while improving nutritional quality is still an area of active research. There are limited data on the formulation of oleogels using soybean oil and beeswax. The development of oleogels from soybean oil and beeswax holds potential as a healthier alternative to saturated and trans fats in baked products. Soybean oil is an abundant, low-cost source of unsaturated fatty acids, while beeswax is a natural and edible structuring agent with GRAS (Generally Recognized as Safe) status. Creating a functional oleogel from these components would yield lipid system that combines health benefits with desirable technological characteristics for baking. This study is justified based on nutritional perspective. From health perspective, the substitution of traditional fats with oleogels would contribute to reduced saturated fat intake and better cardiovascular outcomes. The objective of the study was to develop oleogels from soybean oil and beeswax blends and to evaluate their quality.

MATERIALS AND METHODS

Source of raw materials

Refined beeswax was purchased from Chisco Organics and Essential Oils with Head Office at 11a, Kazeem Street, Ojota, Lagos State, Nigeria. Refined soybean oil was purchased from a confectionary store at New Market, Wukari Township, Taraba state, Nigeria. The processing of these materials was carried out at the Food processing Laboratory of the Department of Food Science and Technology, Federal University Wukari, Taraba state, Nigeria.

Preparation of oleogels from soybeans oil and beeswax

The preparation of oleogels was carried out following the procedure described by Bascuas *et al.* (2020), and the formulation of oleogel is given in Table 1. The beeswax was used to substitute 5%, 10% and 15% of soybean oil (Table 1). The mixture was heated at 106^{o}C in a cooking pot to melt beeswax and then, mixed thoroughly using a stirrer for 30 min to fully dissolve the oleogelator (beeswax). The homogenized aqueous mixture was cooled rapidly to ambient temperature (34^{o}C) to induce nucleation and crystal growth, which lead to the formation of self-assembled networks and thereafter, dried in a hot air oven at 50^{o}C for 24 h.

Table 1 Preparation of oleogel from soybeans oil and beeswax

Soybean oil (g)	Beeswax (g)	Temperature (^{o}C)	Drying time (hour)
95	5	106	24
90	10	106	24
85	15	106	24

Storage stability of oleogels

The oleogel samples were stored at ambient temperature (34^{o}C) and RH of 65% for 90 days. On days 0, 30, 60, and 90, the pH and perioxide value (PV) of the samples were determined

Analytical Methods

Characterization of Oleogels

Determination of color properties of oleogels

Colours of the oleogels were measured by CIELab system using the reflection method by means of Konika-Minolta 200 device (Moghtadaei *et al.*, 2018). To compare

colour differences between the soybean fat and the gels produced, the total colour differences (ΔE) were calculated as:

$$\Delta E = [(L_p *-L_x *)^2 + (a_p *-a_x *)^2 + (b_p *-b_x *)^2]^{0,5}$$

Where: L_p- L parameter of soybean fat

L_x- L parameter of tested oleogel

a_p -a parameter of soybean fat

a_x –a parameter of tested oleogel

b_p- parameter b of palm fat

b_x - parameter b of tested oleogel

Texture analysis

Texture of the oleogel samples was analyzed with TX.AT plus (Micro Stable Systems, UK), using penetration testing. A cylindrical tip with a diameter of 1cm (P/0.5R) was used for the purpose of measurements, dipped 5mm into a sample, with the working component moving at a rate of 1mm/s. The test was carried out at room temperature. The resulting curves (penetration force over time) served to determine hardness and viscosity of the samples. The maximum measured force was defined as hardness and the minimum force as stickiness.

Determination of pH of oleogels

This was determined using a digital pH meter (Model HI 2210, Hanna Instrument Inc., USA). Standardization of the pH meter was carried out using buffer solutions of pH 7 and 4. The oleogel sample (1.5 g) was dissolved in a beaker with 10 ml of distilled water and stirred properly. The pH meter was inserted into the solution and the reading was taken.

Determination of peroxide value of oleogels

As a marker of primary products of lipid oxidation, peroxide value (PA) was determined by the method described by Diaz *et al.* (2003) with some modifications. Lipid

hydroperoxides was extracted by mixing 0.3 g of sample with 1.5 mL of 3:1 isooctane/2-propanol, vortexed, and centrifuged for 2 min at 1000× g. The upper layer (0.2 mL) was collected and 2.8 mL of 2:1 methanol/butanol was added. Then, 30 µL of thiocyanate-ferrous solution was added as an indicator and then, the absorbance was measured at 510 nm using a spectrophotometer (Multiskan Go Spectrophotometer, Thermo Scientific, Vantaa, Finland). Hydroperoxide content was determined using a standard curve prepared with known concentrations of cumenehydroperoxides (0–100 mM).

Determination of p-Anisidine value of oleogels

The AOAC (2020) method was employed to determine the p-AV value of oleogel-oil samples. A 0.5 g sample was dissolved in 25 mL of isooctane. Subsequently, 5 mL of this mixture was transferred into a flask, and 1 mL of p-AV solution was added. The solution was incubated in the dark for 10 min, after which the absorbance was measured at 350 nm against the isooctane solution using a spectrophotometer (UV 160A, Shimadzu, Japan). The p-AV value was calculated as:

p-AV = $25 \times 1.2 \times (A2 - A1)/m$

Determination of total oxidation (TOTOX) value of oleogels

Total oxidation (TOTOX) values of each sample was calculated based on peroxide value (PV) and p-Anisidine value (AV) (AOAC, 2010) as:

$$TOTOX = 2PV + AV$$

Experimental and Statistical Analysis

The experiment was carried out in completely randomized design. The collected data were analyzed by analysis of Variance (ANOVA) to determine the differences between means using SPSS (Statistical Package for Science Solution) Version 26. Significance differences were separated using the Duncan multiple range test. Significance was accepted at $p<0.05$.

RESULTS

Table 2: Colour properties of oleogels from soybean oil and beeswax blends

Oleogel (Soybean : Beeswax)	L*	a*	b*	ΔE	ΔC
100:0	46.43^{a}±1.32	0.43^{c}±0.32	18.95^{c}±0.64	4.28^{d}±0.11	18.96^{c}±0.64
95:5	43.28^{a}±3.97	0.87^{c}±0.96	23.89^{bc}±0.50	5.82^{b}±0.00	23.91^{bc}±0.47
90:10	40.52^{b}±1.62	4.50^{b}±2.05	30.16^{b}±2.83	5.45^{c}±0.00	30.52^{b}±3.10
85:15	43.54^{a}±0.31	9.71^{a}±2.73	41.21^{a}±5.47	8.65^{a}±0.00	42.36^{a}±5.92

Values are means ± standard deviation of two replicates. Means within a column with different superscripts are significantly different ($p<0.05$). L*= lightness value, a*= redness/greenness value, b*= yellowness/blueness value, ΔE= total colour difference, ΔC= chroma difference (colour intensity).

Table 3: Texture properties of oleogels sample from soybean oil and beeswax blends

Oleogel (Soybean : Beeswax)	
100:0	Very soft, watery, oily, smooth, non-sticky and highly spreadable
95:5	Soft, watery, smooth, Non sticky and easily Spreadable
90:10	Soft, Jelly, Sticky, smooth in consistency and easily Spread
85:15	Mildly thick, Sticky, soft, Smooth in consistency and easily spreadable

Table 4: Physicochemical properties of oleogels from soybean oil and beeswax blends

Oleogel (Soybean : Beeswax)	Ph	Peroxide value (mEq/kg)	p-Anisidine value (mEq/kg)	Total oxidation (TOTOX) value
100:0	6.03^{a}±0.67	64.00^{a}±1.41	1.45^{d}±0.07	129.45^{a}±2.90
95:5	6.35^{a}±0.07	60.00^{ab}±0.00	1.95^{c}±0.07	121.95^{ab}±0.07
90:10	6.00^{b}±0.14	50.00^{b}±0.00	2.50^{b}±0.00	102.50^{b}±0.00
85:15	5.80^{b}±0.00	25.00^{b}±7.07	3.15^{a}±0.07	$53.15^{c\pm}$14.07

Values are means ± standard deviation of two replicates. Means within a column with different superscripts are significantly different ($p<0.05$).

Table 5: PH and peroxide value of oleogels from soybean oil and beeswax blends during storage

Oleogels	Storage period (days) 0	30	60	90
		PH		
100:0	6.45^{a}±0.07	6.31^{a}±0.01	6.11^{a}±00.01	5.91^{a}±0.01
95:5	6.34^{b}±0.02	6.13^{b}±0.04	6.02^{b}±0.02	5.83^{b}±0.04

Oleogels	0	Storage period (days) 30	60	90
90:10	6.03^{c}±0.04	5.83^{c}±0.04	5.73^{c}±0.04	5.62^{c}±0.02
85:15	5.78^{d}±0.04	5.64^{d}±0.02	5.48^{d}±0.04	5.68^{d}±0.22
		Peroxide Value		
100:0	4.10^{a}±0.14	6.10^{a}±0.14	9.10^{a}±0.14	11.70^{a}±00.14
95:5	3.55$^{b\pm}$0.07	5.70^{b}±0.14	8.75^{a}±0.07	9.85^{b}±0.07
90:10	3.15^{c}±0.07	5.05^{c}±0.07	7.65^{b}±0.21	9.10^{c}±0.14
85:15	2.75^{d}±0.07	4.75^{c}±0.07	6.65^{c}±0.07	8.60^{d}±0.14

alues are means ± standard deviation of two replicates. Means within a column with different superscripts are significantly different ($p<0.05$).

DISCUSSION

Colour Properties of Oleogels from Soybean Oil and Beeswax Blends

The colour characteristics of oleogels prepared from different soybean oil and beeswax blends revealed significant ($p<0.05$) variations in lightness (L*), redness (a*), yellowness (b*), total colour difference (ΔE), and chroma difference (ΔC) as shown in Table 2. These changes demonstrate that increasing beeswax concentration substantially influenced the visual appearance of the oleogels. Colour is a critical quality attribute because it affects consumer perception and acceptability of fat-based food ingredients and the final baked products in which they are incorporated.

The lightness (L*) values ranged from 40.52 to 46.43. The control sample (100% soybean oil) had the highest lightness (46.43), while the blend containing 10% beeswax had the lowest value (40.52), indicating a darker appearance following beeswax incorporation. Although, the blend containing 15% beeswax showed a slight increase in L* compared with the blend containing 10% beeswax, the general trend suggests that higher beeswax levels reduce lightness because beeswax contains natural pigments such as carotenoids and flavonoids, which impart a creamy yellow colour. Similar observations were reported by Patel *et al.* (2020), who found that increasing concentrations of natural waxes decreased the lightness of vegetable oil oleogels due to enhanced crystal formation and greater light scattering. Similarly, Silva *et al.* (2022) observed reduced L* values in beeswax-based oleogels formulated from sunflower oil.

The redness (a*) values increased significantly ($p<0.05$) from 0.43 in the control to 9.71 in the blend containing 15% beeswax, indicating a gradual shift toward the red region of the colour spectrum with increasing beeswax concentration. This increase may be attributed to the accumulation of coloured compounds naturally present in beeswax and changes in crystal morphology that influence light reflection. Similar increases in a* values with higher wax concentrations have been documented in oleogel systems prepared with beeswax and rice bran wax (Ferro *et al.*, 2023).

A comparable trend was observed for yellowness (b*), which increased from 18.95 to 41.21 as beeswax concentration increased. Beeswax naturally possesses yellow pigments, mainly carotenoids, which become more pronounced at higher concentrations. Elevated b* values have also been reported in beeswax-structured oleogels by Martins *et al.* (2021), who concluded that the inherent colour of beeswax significantly contributes to the yellowness of oleogel matrices.

The total colour difference (ΔE) and chroma difference (ΔC) also increased significantly with increasing beeswax levels. The highest ΔE (8.65) and ΔC (42.36) were recorded in the 85:15 blend, indicating greater deviation from the control and a more intense colour. Higher chroma values reflect increased colour saturation, suggesting that beeswax not only changes the hue but also enhances colour intensity. According to Yılmaz and Öğütcü (2021), increased wax concentration promotes denser crystal networks that alter optical properties and produce more vivid colours in oleogel systems. Overall, the findings indicate that beeswax concentration significantly influences the colour quality of soybean oil oleogels, with higher concentrations producing darker, more yellow, and more intensely coloured oleogels. These colour modifications are expected to influence the appearance of bread produced with oleogel as a shortening substitute while maintaining the natural origin of the fat structuring agent.

Texture Properties of Oleogels Sample from Soybean Oil and Beeswax Blends

The texture properties of oleogels formulated from soybean oil and beeswax blends demonstrated noticeable changes as the concentration of beeswax increased as shown in Table 3. The control sample (100%), was described as very soft, watery, oily, smooth, non-sticky, and highly spreadable. This observation is expected because liquid soybean oil lacks a three-dimensional crystalline network capable of entrapping oil molecules, resulting in a

free-flowing liquid with minimal structural integrity. Similar findings have been reported by Patel *et al.* (2020), who noted that vegetable oils without oleogelators exhibit low firmness and cannot function effectively as solid fat substitutes in bakery products.

The incorporation of 5% beeswax transformed the liquid oil into a soft oleogel that remained watery and smooth but retained its non-sticky nature while being easily spreadable. This improvement indicates the initiation of crystal network formation by beeswax molecules, which immobilize the liquid oil through physical interactions rather than chemical modification. Beeswax contains long-chain wax esters, hydrocarbons, and fatty alcohols that crystallize upon cooling to form a stable three-dimensional network capable of entrapping large amounts of liquid oil (Hwang *et al.*, 2022). Such structural development enhances handling properties while preserving spreadability, an important characteristic for bakery fat applications.

Increasing beeswax concentration to 10% further modified the texture, producing a soft, jelly-like oleogel with noticeable stickiness while maintaining smooth consistency and ease of spreading. The jelly-like texture reflects the development of a denser crystal network that increases gel strength and elasticity. The appearance of stickiness may be attributed to stronger intermolecular interactions and higher crystal density, which increase resistance to deformation during handling. Similar textural transitions have been reported by Ferro *et al.* (2023), who observed that increasing beeswax concentration significantly enhanced firmness and cohesiveness while reducing oil mobility in edible oleogels.

At the highest beeswax concentration (85:15, oil:beeswax), the oleogel became mildly thick, sticky, soft, smooth, and easily spreadable. The increased thickness indicates a stronger and more continuous crystalline matrix capable of retaining oil more effectively. Despite the higher viscosity and stickiness, the oleogel maintained satisfactory spreadability, suggesting that the formulation achieved a desirable balance between firmness and workability. According to Yılmaz and Öğütcü (2021), higher wax concentrations generally increase hardness and viscosity because additional crystalline junctions strengthen the gel network, thereby improving the functional performance of oleogels as shortening replacements in baked products.

The results demonstrate that beeswax concentration plays a significant role in determining the texture of soybean oil oleogels. Progressive increases in beeswax transformed the system from a liquid oil into a semi-solid gel with improved structural

stability, enhanced consistency, and acceptable spreadability. These textural modifications are advantageous for bread production because they provide the rheological properties required for dough incorporation while offering a healthier alternative to conventional saturated and hydrogenated fats. The findings agree with recent studies highlighting beeswax as an effective natural oleogelator for developing functional fat replacers suitable for bakery applications.

Physicochemical Properties of Oleogels from Soybean Oil and Beeswax Blends

The physicochemical properties of oleogels prepared with varying concentrations of beeswax showed significant ($p<0.05$) differences in pH, peroxide value (PV), p-anisidine value (p-AV), and total oxidation (TOTOX) value as shown in Table 4. These parameters are widely used to assess the oxidative stability and quality of edible oils and oleogel systems, particularly during product development for bakery applications. The observed changes indicate that beeswax concentration influenced both the chemical stability and oxidation behaviour of the formulated oleogels.

The pH values ranged from 5.80 to 6.35, indicating that all formulations remained slightly acidic to nearly neutral. Although, the control sample (100% soybean oil) and the blend containing 5% beeswax exhibited relatively higher pH values, a slight reduction was observed with increasing beeswax concentration. This decline may be associated with naturally occurring free fatty acids and minor acidic constituents present in beeswax, as well as interactions between the wax crystal network and the oil phase. Nevertheless, the narrow pH range suggests that oleogel formation did not markedly alter the acidity of soybean oil. Similar pH stability has been reported in vegetable oil oleogels, where gelation primarily modifies physical structure rather than chemical composition (Da Pieve *et al.*, 2022).

Peroxide value, which measures the concentration of primary lipid oxidation products, decreased substantially from 64.00 meq O_2/kg in the control sample to 25.00 meq O_2/kg in the blend containing 15% beeswax. This reduction demonstrates that increasing beeswax concentration enhanced the oxidative stability of soybean oil by limiting oxygen diffusion and restricting lipid oxidation Lim *et al.* (2023). The crystalline network formed by beeswax effectively immobilized liquid oil, reducing molecular mobility and slowing the formation of lipid hydroperoxides. Similar findings were reported by Lim *et al.*

(2023), who observed significantly lower peroxide values in beeswax-structured canola oil oleogels due to improved barrier properties against oxidative deterioration.

The p-anisidine value increased from 1.45 in the control to 3.15 in the 85:15 (oil:beeswax) formulation. The p-anisidine value measures secondary oxidation products, mainly aldehydes produced from the decomposition of hydroperoxides. The slight increase observed with higher beeswax concentrations may reflect the gradual breakdown of previously formed primary oxidation products rather than extensive oxidation. Despite this increase, the p-anisidine values remained relatively low, indicating limited accumulation of secondary oxidation compounds and suggesting that the oleogels maintained acceptable chemical quality throughout formulation. Similar trends have been documented in wax-based oleogels during storage, where hydroperoxide decomposition occurred alongside overall improved oxidative stability (Co & Marangoni, 2021).

The total oxidation (TOTOX) value, which provides a comprehensive measure of overall lipid oxidation, declined markedly from 129.45 in the control sample to 53.15 in the blend containing 15% beeswax. This substantial reduction confirms that beeswax effectively protected soybean oil against oxidative deterioration. Lower TOTOX values indicate better preservation of oil quality and longer shelf stability, which are desirable characteristics for bakery shortenings and fat replacers. According to Calligaris *et al.* (2021), oleogelation significantly reduces total oxidative degradation by creating a stable crystalline matrix that minimizes exposure of unsaturated fatty acids to oxygen and pro-oxidant agents. Overall, these findings demonstrate that increasing beeswax concentration improved the physicochemical stability of soybean oil oleogels, particularly by reducing primary and overall oxidation, thereby enhancing their suitability as healthier lipid alternatives in bread production.

Storage properties of oleogels from soybean oil and beeswax blends

The storage stability of soybean oil beeswax oleogels was evaluated over a 90-day period using pH and peroxide value as indicators of chemical stability and lipid oxidation as shown in Table 5. The results showed significant ($p<0.05$) changes in both parameters throughout storage, with beeswax concentration playing an important role in preserving the quality of the oleogels. These findings demonstrate that the structural network created by beeswax contributed to improved oxidative stability during storage.

The pH values of all samples gradually declined as storage progressed from Day 0 to Day 90. The control sample (100% soybean oil) decreased from 6.45 to 5.91, while the PH of blends containing 5% and 10% beeswax declined from 6.34 to 5.83 and 6.03 to 5.62, respectively. The blend containing 15% beeswax exhibited the lowest pH values throughout storage, changing from 5.78 to 5.68. The gradual reduction in pH may be attributed to the formation of free fatty acids and other acidic compounds resulting from mild hydrolytic and oxidative reactions occurring during storage. However, the relatively small decline observed in all formulations indicates that the oleogels remained chemically stable over the storage period. Similar observations were reported by Bascuas *et al.* (2023), who found that beeswax-based oleogels experienced only slight reductions in pH during ambient storage because the wax crystal network restricted moisture migration and slowed hydrolytic deterioration.

Peroxide value increased progressively in all samples during storage, indicating the gradual formation of primary lipid oxidation products. The control sample showed the greatest increase, rising from 4.10 meq O_2/kg at Day 0 to 11.70 meq O_2/kg after 90 days. In contrast, the oleogels containing beeswax exhibited lower peroxide values throughout storage, with the 15% beeswax formulation recording the lowest increase from 2.75 to 8.60 meq O_2/kg. This trend suggests that increasing beeswax concentration effectively delayed lipid oxidation by limiting oxygen penetration into the oil phase and stabilizing unsaturated fatty acids within the crystalline matrix. The denser gel network formed at higher beeswax concentrations likely reduced molecular mobility and restricted the propagation of oxidative reactions. Similar results were reported by Chaves *et al.* (2022), who observed enhanced oxidative stability and significantly lower peroxide values in sunflower oil oleogels containing higher concentrations of natural waxes during prolonged storage.

The superior oxidative stability of the blend containing 15% beeswax indicates that increasing beeswax concentration strengthened the protective crystalline network surrounding soybean oil. Such protection is particularly important because soybean oil is rich in polyunsaturated fatty acids, which are highly susceptible to oxidative deterioration. According to Okuro *et al.* (2021), wax-based oleogels effectively reduce oxygen diffusion and improve storage stability by physically entrapping liquid oil within a continuous crystal network, thereby extending product shelf life.

The storage study demonstrates that although slight chemical changes occurred over the 90-day period, oleogels formulated with higher beeswax concentrations maintained better quality than the control. The lower peroxide values and relatively stable pH observed in the blend containig 15% beeswax suggest enhanced resistance to oxidation and hydrolysis, making this formulation more suitable for bakery applications requiring extended storage stability. These findings further support the potential of beeswax oleogels as functional and stable alternatives to conventional solid fats in bread production.

CONCLUSION

This study successfully developed oleogels from soybean oil structured with beeswax and evaluated their quality. The results of the study demonstrated that increasing beeswax concentration improved the structural integrity and oxidative stability of the oleogels by reducing peroxide and total oxidation values while producing stable semi-solid systems suitable for bakery applications. The oleogels also exhibited desirable colour and texture characteristics, confirming the effectiveness of beeswax as a natural oleogelator.

Recommendations

Based on the findings of this study, the oleogel containing 85% soybean oil and 15% beeswax is recommended for use in bakery applications because it exhibited the most favourable colour characteristics, texture, oxidative stability, and storage stability.

Further studies should evaluate the performance of the oleogel containing 15% beeswax in different bakery products and to assess shelf life of the products under different storage conditions.

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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REFERENCES

Abdel-Moemin, A. R., Regenstein, J. M., & Abdel-Rahman, M. K. (2018). New food products for sensory-compromised situations. *Comprehensive Reviews in Food Science and Food Safety, 17*(6), 1625–1639. https://doi.org/10.1111/1541-4337.12399

AOAC International. (2010). *Official methods of analysis of AOAC International* (18th ed., rev. 3).

AOAC. (2020). *Official methods of proximate analysis* (17th ed.).

Bascuas, S., Hernando, I., Moraga, G., & Quiles, A. (2020). Structure and stability of edible oleogels prepared with different unsaturated oils and hydrocolloids. *International Journal of Food Science & Technology, 55*(4), 1458–1467. https://doi.org/10.1111/ijfs.14469

Bascuas, S., Salvador, A., Hernando, I., & Quiles, A. (2023). Stability and quality changes of beeswax-based oleogels during storage: Implications for food applications. *Food Hydrocolloids, 139*, Article 108512.

Blake, A. I., & Marangoni, A. G. (2015). Factors affecting the rheological properties of a structured cellular solid used as a fat mimetic. *Food Research International, 74*, 284–293. https://doi.org/10.1016/j.foodres.2015.04.045

Calligaris, S., Manzocco, L., & Nicoli, M. C. (2021). Lipid oxidation in oleogels: Mechanisms, stability and implications for food applications. *Food Research International, 147*, Article 110548.

Chaves, K. F., Barrera-Arellano, D., & Ribeiro, A. P. B. (2022). Influence of natural wax concentration on oxidative stability and storage behaviour of vegetable oil oleogels. *Food Chemistry, 387*, Article 132891.

Co, E. D., & Marangoni, A. G. (2012). Organogels: An alternative edible oil-structuring method. *Journal of the American Oil Chemists' Society, 89*(5), 749–780. https://doi.org/10.1007/s11746-012-2049-3

Colla, K., Costanzo, A., & Gamlath, S. (2018). Fat replacers in baked food products. *Foods, 7*(12), Article 192. https://doi.org/10.3390/foods7120192

Da Pieve, S., Calligaris, S., Panozzo, A., & Nicoli, M. C. (2022). Physicochemical and oxidative characteristics of natural wax oleogels prepared from vegetable oils. *LWT – Food Science and Technology, 161*, Article 113356.

Dassanayake, L. S. K., Kodali, D. R., & Ueno, S. (2011). Formation of oleogels based on edible lipid materials. *Current Opinion in Colloid & Interface Science, 16*(5), 432–439. https://doi.org/10.1016/j.cocis.2011.05.005

Domínguez, R., Lorenzo, J. M., Pateiro, M., Munekata, P. E. S., Alves dos Santos, B., Basso Pinton, M., Cichoski, A. J., & Bastianello Campagnol, P. C. (2024). Main animal fat replacers for the manufacture of healthy processed meat products. *Critical Reviews in Food Science and Nutrition, 64*(9), 2513–2532. https://doi.org/10.1080/10408398.2022.2124397

Ferdaus, M. J., Barman, B., Mahmud, N., & da Silva, R. C. (2024). Oleogels as a promising alternative to animal fat in saturated fat-reduced meat products: A review. *Gels, 10*(2), Article 92. https://doi.org/10.3390/gels10020092

Ferro, A. C., Nunes, M. C., & Rodrigues, J. B. (2023). Development and characterization of beeswax-based oleogels for bakery applications. *Food Structure, 37*, Article 100338.

Hooper, L., Abdelhamid, A., Bunn, D., Brown, T., Summerbell, C. D., & Skeaff, C. M. (2015). Effects of total fat intake on body weight. *Cochrane Database of Systematic Reviews, 2015*(8), Article CD011834. https://doi.org/10.1002/14651858.CD011834

Hwang, H. S., Singh, M., & Lee, S. (2022). Natural wax-based oleogels: Structure, functionality and food applications. *Food Hydrocolloids, 124*, Article 107281.

Lim, J., Kim, Y., & Lee, S. (2023). Oxidative stability and structural characteristics of beeswax-based canola oil oleogels during storage. *Food Chemistry, 404*, Article 134712.

Liu, A. G., Ford, N. A., Hu, F. B., Zelman, K. M., Mozaffarian, D., & Kris-Etherton, P. M. (2017). A healthy approach to dietary fats: Understanding the science and taking action to reduce consumer confusion. *Nutrition Journal, 16*(1), Article 53. https://doi.org/10.1186/s12937-017-0271-4

Martins, A. J., Vicente, A. A., & Cunha, R. L. (2021). Beeswax oleogels as sustainable alternatives to solid fats: Structure, functionality and food applications. *Current Opinion in Food Science, 40*, 78–85.

Moghtadaei, M., Soltanizadeh, N., & Goli, S. A. H. (2018). Production of sesame oil oleogels based on beeswax and application as partial substitutes of animal fat in beef burger. *Food Research International, 108*, 368–377. https://doi.org/10.1016/j.foodres.2018.03.051

Okuro, P. K., Malfatti-Gasperini, A. A., & Cunha, R. L. (2021). Oleogels: Structuring edible oils with natural waxes for improved oxidative stability and food applications. *Current Opinion in Food Science, 41*, 90–97.

Patel, A. R., Schatteman, D., De Vos, W. H., & Dewettinck, K. (2020). Edible oleogels based on natural waxes: Structure, functionality and applications in food products. *Comprehensive Reviews in Food Science and Food Safety, 19*(6), 3357–3383.

Pinto, T. C., Martins, A. J., Pastrana, L., Pereira, M. C., & Cerqueira, M. A. (2021). Oleogel-based systems for the delivery of bioactive compounds in foods. *Gels, 7*(3), Article 86. https://doi.org/10.3390/gels7030086

Silva, T. J., Martins, M. A., & Arellano, D. B. (2022). Physical and optical properties of sunflower oil oleogels structured with beeswax. *LWT – Food Science and Technology, 154*, Article 112686.

Yılmaz, E., & Öğütcü, M. (2021). The influence of wax concentration on the physicochemical and colour characteristics of edible oleogels. *Journal of Food Processing and Preservation, 45*(8), Article e15634.