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Development of oleogel by structuring the blend of corn oil and sunflower oil with beeswax to replace margarine in cookies

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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

Oleogel significantly affects the product's sensory properties, texture, and shelf life. The goal of this study was to create oleogel by combining corn oil and sunflower oil and utilizing beeswax as a structural agent. A variety of physicochemical analyses were done to evaluate the quality of oleogel, including peroxide value, iodine value, saponification value, fatty acid, rheological parameters and firmness. Different percentages of oleogel, ranging from 0% to 75%, were used to substitute margarine in cookies. The cookies' quality was evaluated using proximate analysis, color analysis, texture analysis, calorific value, and sensory analysis. The study yielded substantial results by finding the ideal margarine-to-oleogel mix ratio, allowing for the manufacturing of high-quality cookies with a greater degree of unsaturation. Cookies with oleogel showed higher levels of unsaturation and better properties, making them the preferred option among consumers.

1. Introduction

In the food system, multiple ingredients function together to give food its flavor, texture, and nutritional value. Some of these ingredients, like lipids, give the finished product its flavor and texture. They naturally occur in two states: solid fat and liquid oil. Solid fat is more stable against oxidation and has a longer shelf life than liquid oil (Al-Hoshani et al., 2023; Andualem, 2023; Dohouonan et al., 2022; Jimayu, 2022; Mohammad et al., 2023; Sharma et al., 2023). Solid fats are used by the food industry to produce a variety of food products, including dairy, meat, baked goods, and confections. These fats give food products their desired mouthfeel, palatability, sensory and functional properties such as plasticity and hardness (Thakur et al., 2022).

Shortening, margarine and butter are solid fats commonly utilized in bakeries and confectionery sectors due to their ability to impart a unique flavor and the desired sensory attributes to the products. However, these solid fats contain extremely high levels of saturated fatty acids and potentially harmful trans fatty acids, which have been linked to an increased risk of obesity, diabetes and cardiovascular disease. Hence, it is essential to create a novel solid fat substitute that contains no trans-fatty acids and has minimal levels of saturated fatty acids (Pang et al., 2023).

The solidification of liquid oils through the oleogelation process provides a viable substitute for solid fats obtained with chemical transformations and thus can eliminate or substitute them in food products. Despite being the focus of ongoing research, oleogels have the potential to serve as a functional food additive while preserving the nutritional value of oils, in addition to being an excellent substitute for commercially available solid fats like margarine and butter. Oleogels have numerous potential applications in the food industry, particularly in baking and confectionery, where they can effectively substitute hydrogenated fats (Banaś et al., 2024). Oleogels are gel-like structures composed of lipids, where the liquid component is predominately oil. Oleogelators are compounds that can produce oleogels by trapping oil within a three-dimensional framework (Naeli et al., 2022). Oleogelation does not alter the unsaturated profile, nor does it make use of any chemicals in order to transform the liquid oil into a gel network. As a result, it reduces the negative effects of saturated fats while

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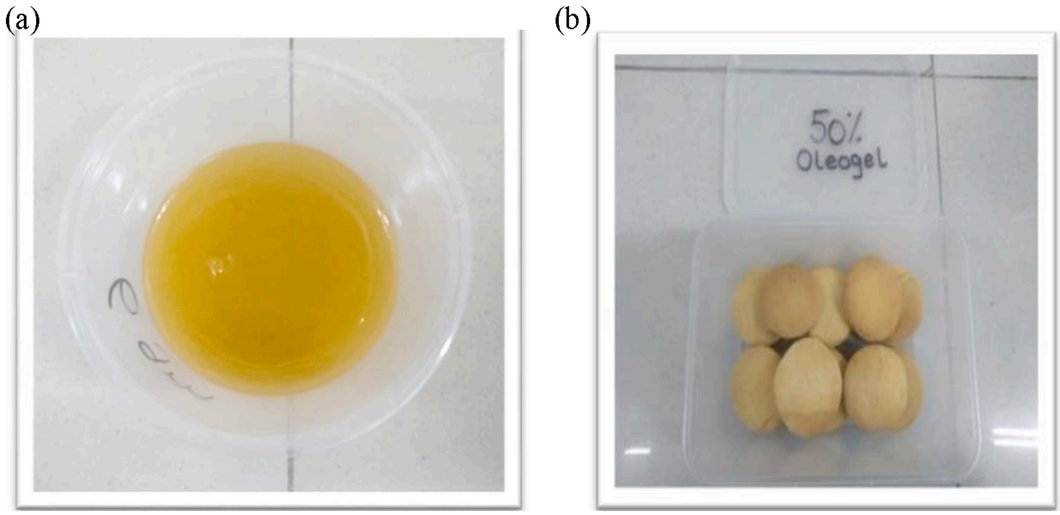

Fig. 1. (a) Oleogel developed by structuring corn oil and sunflower oil with beeswax.
(b) Cookies formulated by utilizing oleogel containing corn oil, sunflower oil and beeswax.

simultaneously offering the nutritional advantages of unsaturated fats (Thakur et al., 2022).

Oils play an important role to recover the different diseases in the animals and attained better results (Çalışkan & Emin, 2023; Ündağ & Dönmez, 2023. Bangulzai et al., 2022; Salman & Imran, 2022; Batool et al., 2023). Among these, sunflower oil comprises approximately 80% unsaturated fatty acids. Sunflower oil is abundant in essential fatty acids, particularly oleic acid, which makes up 85–95% of the total fatty acids present (Qammar-uz-Zaman et al., 2023). Corn is highly nutritious due to its composition, which includes 72% carbohydrate, 10% protein, 4.8% oil, 3.0% sugar, 1.7% ash, and 9.50% fiber (Khalid et al., 2022). Beeswax is commonly used as a gelling agent to solidify vegetable oil since it is highly effective at gelling. The main components of this substance include esters, free acids, free alcohols and hydrocarbons (Shang et al., 2021). Cookies are a highly popular food item that falls within the bakery classification and is commonly consumed. The inclusion of fat substitution in cookies has the potential to contribute to the creation of a healthier product that has a longer shelf life (Quilaqueo et al., 2022). The objective of the present research is to evaluate the properties of oleogel produced by combining sunflower oil, corn oil, and beeswax in order to investigate how well consumers like the cookies made from the oleogel. Substituting margarine with oleogel in cookie recipes can effectively decrease the amount of saturated fat present, resulting in a healthier and more nutritious product.

2. Materials and methods

This study was conducted at the National Institute of Food Science and Technology (NIFSAT), University of Agriculture, Faisalabad, Pakistan. Sunflower oil, corn oil and raw material for cookies were purchased from the local market of Faisalabad. Beeswax was acquired from a scientific store in Faisalabad.

2.1. Preparation of oleogel

The procedure for making oleogel was performed as described by Scharfe et al. (2022) with few variations. A 500 mL Pyrex glass beaker was filled with a mixture of sunflower oil and corn oil, with sunflower oil accounting for 75% and corn oil accounting for 25% based on weight (*w*/w). The beeswax was measured and incorporated into the mixture of oils at a concentration of 6% by weight. The beaker containing oil blends and beeswax was put on the hot plate, along with a thermometer and then the heating was begun until the temperature reached 90 °C. The mixture was then allowed to set at room temperature overnight to develop oleogel. After the formation of oleogel, it was stored in the refrigerator at a temperature of 4–5 °C. Fig. 1a shows the oleogel developed by structuring corn oil and sunflower oil with beeswax.

2.2. Analysis of oleogel

Physicochemical and antioxidant analysis of oleogel was performed.

2.2.1. Physicochemical analysis

2.2.1.1. Rheological measurements of oleogel. The rheological parameters were measured using a controlled stress rheometer with parallel plated (40 mm diameter), following the method described by Jang et al. (2015). The rheological properties of oleogel were investigated in relation to temperature variations. The viscosity was determined by heating the oleogel to 50 °C and thereafter placing it onto the Peltier Plate of the rheometer. The temperature gradually increased from 50 to 70 °C at a rate of 2 °C per min. A comparative analysis was conducted to assess the rheology of oleogel in relation to margarine.

2.2.1.2. Firmness test, solid fat content, iodine value, saponification value, peroxide value. The firmness of the oleogel was assessed using the puncture test through texture analyzer (TMS-Pro, Food Technology Co., Virginia, USA) equipped with a 25 N load cell, following the methodology established by Jang et al. (2015). The solid fat content (SFC), which represents the proportion of solid fat, was determined using the identical methods as described by Jung et al. (2020) using nuclear magnetic resonance (NMR) (Oxford MQC+, Oxon, UK). The iodine value (IV) was determined by the protocol described in the (AOCS, 2017) Official Method Cd. 1d-92. The saponification value (SV) was determined by methodology of (AOCS, 2017) Official Method Cd. 3–25. The peroxide value (PV) of oleogel was determined using the methods outlined in the (AOCS, 2017) Official methods Cd. 8b-90.

2.2.2. Antioxidant tests

The DPPH radical scavenging assay was used to measure the antioxidant activity of oleogel using the 2,2-diphenyl-1 picrylhydrazyl (DPPH) radical scavenging assay as explained by Silva et al. (2022) and total phenolic content (TPC) using a 1:10 (*w*/*v*) extraction ratio in 80% (*v*/v) methanol in which Folin-Ciocalteau reagent was used to measure the sample TPC as determined by following the method of Martinović et al. (2020).

Table 1
Rheology, firmness and SFC of oleogel and margarine.

Parameters	Viscosity (Pa.s)			Firmness (N)	SFC (%)
	50 °C	60 °C	70 °C		
Oleogel	0.065 ± 0.005^{a}	0.054 ± 0.004^{ab}	0.042 ± 0.007^{bc}	1.33 ± 0.05^{b}	3.33 ± 0.02^{b}
Margarine	0.049 ± 0.003^{bc}	0.044 ± 0.002^{bc}	0.039 ± 0.004^{c}	7.25 ± 0.27^{a}	12.09 ± 0.20^{a}

Mean values not sharing same letter are statistically different ($P < 0.05$).

2.2.3. Fatty acid analysis by GC-FID system

Fatty acid content was determined according to the methodology of Pehlivanoğlu et al. (2018) with some modifications, using GC-FID (Agilent 6890-GC, USA) fitted with an HP-88 column (100 m × 0.25 mm ID × 0.2 μm).

2.3. Preparation of cookies

After raw material preparation, margarine and oleogel in varied concentrations were used to make cookies. Oleogel cookies were made by weight-based substitution of margarine. Four treatments T_0, T_1, T_2, and T_3 were created with 100% margarine, 25% oleogel, 50% oleogel and 75% oleogel, respectively. A modified version was used to make cookies (Jang et al., 2015). Fig. 1b shows the cookies formulated by using oleogel containing corn oil, sunflower oil and beeswax.

2.4. Analysis of cookies

The cookies were evaluated for their proximate, calorific, textural, color and sensory analysis.

2.4.1. Proximate analysis

The oleogel cookies were subjected to moisture analysis (AACC Method No. 44-15 A), total ash (AACC Method No. 08–01), crude fat (AACC Method No. 30–25), crude protein (AACC Method No. 46–10), crude fiber (AACC Method No. 32–10) and Nitrogen free extract (NFE) according to their respective procedures as described in (AACC, 2017).

2.4.2. Calorific value

The calorific value of oleogel cookies was determined by subjecting the samples to bomb calorimeter as employed by (Adeyeye, 2016).

2.4.3. Textural analysis

Textural analysis of cookies was determined by following the methodology of Li et al. (2021). The textural profile of the cookies sample was analyzed using a texture analyzer (T.A.X.T Plus, Stable-Micro-Systems, UK).

2.4.4. Color analysis

The cookies were subjected to color analysis using a colorimeter, following the methodology of Barragán-Martínez et al. (2022).

2.4.5. Sensory evaluation

The consumer acceptance of oleogel cookies for color, flavor, texture, appearance, and overall acceptability was evaluated using the 9-point hedonic scale, as defined by Meilgaard et al. (2016). Faculty members and postgraduate students from NIFSAT took part in the evaluation to select the best treatment combination for oleogel cookies.

2.4.6. Storage study

The stability of cookies was assessed after 1st, 15th, 30th, 45th and 60th day of storage intervals. The texture and sensory analysis demonstrate the stability of cookies.

2.4.7. Statistical analysis

The data gathered from the current study was subjected to statistical analysis to determine its level of significance. The analysis of variance was conducted using a two-way factorial design and mean comparisons were determined by applying the Tukey test (Montgomery, 2017).

3. Results and discussion

3.1. Physicochemical analysis of oleogel

3.1.1. Rheology, firmness and SFC

Viscosity is a flow behavior that is highly essential in oleogel because it can affect the cookie dough formation process in cookie formulation. The flow characteristics of oleogel and margarine were examined at temperatures ranging from 50 to 70 °C. As the temperature increased the viscosity of the samples decreased. The rheological properties of the oleogel were determined by following the method of Jang et al. (2015). The viscosity of oleogel declined in a non-linear pattern and reduced quickly between 50 and 70 °C. Rheological properties of oleogel showed highly significant results. At 50 °C, the margarine had a mean viscosity of 0.049 ± 0.003, which declined to 0.044 ± 0.002 at 60 °C, and finally to 0.039 ± 0.004 at 70 °C. Oleogel showed mean value of 0.065 ± 0.005 at 50 °C, 0.054 ± 0.004 at 60 °C, and 0.042 ± 0.007 at 70 °C. Table 1 demonstrates the viscosity of oleogel and margarine. These results were supported by the study conducted by Giacomozzi et al. (2018) to evaluate the efficacy of oleogels containing high-oleic sunflower oil structured with monoglyceride as a fat replacer in muffins. At a concentration of 7% oleogelator, the oleogel viscosity was determined to be 0.07.

The firmness of oleogel is defined as the force needed to induce a certain deformation. The firmness value of oleogel and margarine was measured in newton (N). Margarine exhibited greater firmness compared to oleogel. Margarine showed the higher firmness value 7.25 ± 0.27.

compared to the oleogel sample, which had a firmness value of 1.33 ± 0.05. Table 1 illustrates the firmness of oleoegl and margarine. The findings were supported by the study carried out by Borriello et al. (2022), to prepare oleogels utilizing pumpkin seed oil and carnauba wax at varying concentrations of 4, 5, 6 and 8%.

The term SFC refers to the proportion of solid constituents in edible fats and oils at a specific temperature. The SFC of both margarine and oleogel was determined in percentage (%) and compared at a temperature of 25 °C. The margarine had a mean value of 12.09 ± 0.2 while the oleogel had a mean value of 3.33 ± 0.02. The findings indicate that the SFC of margarine is significantly higher than that of oleogel. Despite having SFC, the oleogel demonstrated the ability to create self-supporting structures and function as a substitute for margarine during the mixing process of cookie preparation. The SFC value of oleogel and margarine is demonstrated in Table 1. The study conducted by Gao et al. (2023) provided evidence to support the utilization of various waxes at a concentration of 10% for producing oleogels using high oleic sunflower oil, which were then incorporated into cookie formulations.

3.1.2. Iodine value, saponification value and peroxide value

The oil or fat IV or iodine number indicates the degree of unsaturation. The iodine absorption rate is determined by measuring the amount of iodine absorbed per 100 g of fat. The oleogel had an IV that was very close to the oils utilized in its development. The mean value of IV for oleogel was 129.04 ± 4.23 exceeded that of the margarine, indicating an increased number of double bonds in the oleogel and thus a higher degree of unsaturation compared to margarine. Demirkesen and Mert (2019) conducted a study to examine the properties of oleogel made from sunflower oil, and gelation was achieved utilizing beeswax as an oleogelator. The saponification number or SV shows the inverse relationship with the average length of the fatty acids. Particularly, a smaller saponification number corresponds to a larger average length and molecular weight of the fatty acids and vice versa. The mean value of the SV

Table 2
Physicochemical analysis of oleogel (IV, SP, PV, TPC and DPPH).

Sample	Iodine value (g I_2/100g fat)	Saponification value (mg KOH/g fat)	Peroxide value (meq O_2/kg)		TPC (mg GAE/g oil)	DPPH (% inhibition)
			(20 °C)	(4 °C)		
Oleogel	129.04 ± 4.23^{a}	190.50 ± 4.94^{b}	0.28 ± 0.02^{bc}	0.25 ± 0.01^{c}	1.13 ± 0.07^{a}	69.39 ± 3.27^{a}
Margarine	75.14 ± 3.65^{b}	228.30 ± 6.70^{a}	0.36 ± 0.03^{a}	0.32 ± 0.02^{ab}		
Sunflower oil	127.08 ± 4.57^{a}	194.58 ± 5.19^{b}	–		0.80 ± 0.04^{ab}	48.13 ± 2.18^{b}
Corn oil	124.26 ± 3.96^{a}	187.32 ± 4.58^{b}	–		1.02 ± 0.05^{b}	52.06 ± 2.32^{ab}

Mean values not sharing same letter are statistically different ($P < 0.05$).

Table 3
Fatty acid profile of oleogel by GC-FID.

Sr. No.	Fatty acids	Concentration %
1	Solvent (Methanol)	1.2
2	Myristic acid (C14:0)	0.2
3	Palmitic acid (C16:0)	8.1
4	Stearic acid (C18:0)	5.3
5	Oleic acid(C18:1)	24.1
6	Linoleic acid (C18:2)	54.8
7	Arachidic acid (C20:0)	0.4
8	Gadoleic acid (C20:1)	2.4
9	Behenic acid(C22:0)	1.3
10	Lignoceric acid (C24:0)	0.7

for oleogel was 190.50 ± 4.94 (mg KOH/g fat), which was quite similar to the SV values of sunflower oil and corn oil. Sunflower oil had a mean SV of 194.58 ± 5.19 (mg KOH/g fat), while corn oil had a mean SV of 187.32 ± 4.58 (mg KOH/g fat). The research conducted by Holey et al. (2021) further supported the findings of saponification by formulating oleogels using rice bran wax and sunflower wax. Both the IV and SV of the treatment exhibited statistically significant results. The PV was measured to determine and compare the oxidative stability of oleogel and margarine at refrigerated temperature (4 °C) and room temperature (20 °C). The findings indicated that the PV of both oleogel and margarine was somewhat higher at high temperatures as compared to low temperatures. This indicates that the oleogel and margarine demonstrate higher oxidative stability when stored at refrigerated temperature rather than at room temperature. The PV analysis were correlated with the study conducted by Yılmaz et al. (2014) to assess the oxidative stability of oleogels made using hazelnut oil, beeswax and monoglyceride oleogelator at temperatures of 4 °C and 20 °C. The values of IV, SV and PV for oleogel and margarine are presented in Table 2.

3.2. Antioxidant analysis of oleogel

The antioxidant activity of the oleogel was measured by analyzing the TPC and DPPH scavenging activities of the oleogel. The TPC of the sample was determined by calculating the amount of gallic acid in milligrams per gram of the sample (mg GAE/g oil). The oleogel sample exhibited TPC mean value 1.13 ± 0.07 mg GAE/g oil, which was close to and greater than that of sunflower oil. The oleogel showed 69.39 ± 3.27% inhibition of mean value of DPPH. Combining corn oil with sunflower oil enhanced the antioxidant activity of the oleogel. The findings were supported by the study conducted by Mohamed et al. (2014) to ascertain the oxidative stability and radical scavenging activity of corn oil and blends stored under oxidation conditions for a duration of 15 days. The TPC and DPPH values of oleogel were greater compared to those of corn and sunflower oil. Table 2 shows the TPC and DPPH value of oleogel and oils.

3.3. Fatty acid profile of oleogel by GC-FID

In fatty acid composition analysis, the concentration of 13 fatty acids was analyzed in all the samples, including 8 saturated fatty acids such as C12:0, C14:0, C15:0, C16:0, C18:0, C20:0, C22:0, C24:0 and 5

Table 4
Proximate analysis of cookies (moisture content %, ash content %, protein content %, fiber content %, NFE %) 90–21.

Treatment	Storage days 1st day	15th day	30th day	45th day	60th day
Moisture content (%)					
T_0	5.84 ± 0.27^{a}	5.90 ± 0.24^{a}	5.98 ± 0.32^{a}	6.08 ± 0.29^{a}	6.19 ± 0.35^{a}
T_1	3.27 ± 0.18^{f}	3.32 ± 0.14^{ef}	3.43 ± 0.19^{def}	3.55 ± 0.20^{def}	3.69 ± 0.15^{cdef}
T_2	3.85 ± 0.20^{bcdef}	3.92 ± 0.17^{bcdef}	3.98 ± 0.21^{bcdef}	4.05 ± 0.26^{bcde}	4.11 ± 0.28^{bcd}
T_3	4.32 ± 0.24^{bc}	4.39 ± 0.22^{bc}	4.46 ± 0.31^{b}	4.51 ± 0.25^{b}	4.60 ± 0.30^{b}
Ash content (%)					
T_0	0.86 ± 0.06^{a}	0.85 ± 0.04^{a}	0.83 ± 0.07^{ab}	0.82 ± 0.13^{abc}	0.81 ± 0.03^{abcd}
T_1	0.60 ± 0.03^{cde}	0.59 ± 0.08^{de}	0.58 ± 0.12^{e}	0.56 ± 0.02^{e}	0.54 ± 0.10^{e}
T_2	0.61 ± 0.05^{bcde}	0.60 ± 0.09^{cde}	0.59 ± 0.02^{de}	0.57 ± 0.04^{e}	0.55 ± 0.07^{e}
T_3	0.62 ± 0.08^{bcde}	0.61 ± 0.06^{bcde}	0.60 ± 0.01^{cde}	0.58 ± 0.08^{e}	0.56 ± 0.11^{e}
Fat content (%)					
T_0	23.86 ± 1.13^{bcde}	23.75 ± 0.91^{cde}	23.60 ± 1.12^{de}	23.39 ± 1.18^{e}	23.15 ± 1.27^{e}
T_1	27.39 ± 0.68^{a}	27.31 ± 1.30^{ab}	27.22 ± 1.22^{ab}	27.14 ± 0.66^{abc}	27.02 ± 0.82^{abcd}
T_2	28.85 ± 1.34^{a}	28.72 ± 1.25^{a}	28.64 ± 0.75^{a}	28.56 ± 1.39^{a}	28.42 ± 1.28^{a}
T_3	29.43 ± 1.29^{a}	29.30 ± 0.72^{a}	29.19 ± 1.31^{a}	29.11 ± 1.24^{a}	29.03 ± 0.97^{a}
Protein content (%)					
T_0	7.66 ± 0.31^{a}	7.64 ± 0.28^{a}	7.62 ± 0.30^{a}	7.59 ± 0.36^{a}	7.57 ± 0.32^{a}
T_1	7.69 ± 0.37^{a}	7.67 ± 0.26^{a}	7.64 ± 0.34^{a}	7.62 ± 0.27^{a}	7.60 ± 0.33^{a}
T_2	7.71 ± 0.29^{a}	7.69 ± 0.35^{a}	7.67 ± 0.28^{a}	7.64 ± 0.32^{a}	7.62 ± 0.26^{a}
T_3	7.73 ± 0.34^{a}	7.71 ± 0.27^{a}	7.68 ± 0.33^{a}	7.66 ± 0.31^{a}	7.64 ± 0.30^{a}
Crude fiber (%)					
T_0	1.16 ± 0.07^{a}	1.14 ± 0.03^{a}	1.13 ± 0.11^{a}	1.10 ± 0.08^{a}	1.08 ± 0.12^{a}
T_1	1.18 ± 0.04^{a}	1.16 ± 0.06^{a}	1.15 ± 0.02^{a}	1.13 ± 0.03^{a}	1.11 ± 0.08^{a}
T_2	1.19 ± 0.09^{a}	1.17 ± 0.01^{a}	1.16 ± 0.07^{a}	1.14 ± 0.04^{a}	1.12 ± 0.06^{a}
T_3	1.20 ± 0.06^{a}	1.18 ± 0.02^{a}	1.17 ± 0.05^{a}	1.15 + 0.10^{a}	1.14 ± 0.03^{a}
Nitrogen free extract (NFE) (%)					
T_0	60.63 ± 2.6^{a}	60.73 ± 2.41^{a}	60.85 ± 2.58^{a}	61.02 ± 2.47^{a}	61.20 ± 2.43^{a}
T_1	59.87 ± 2.45^{a}	59.94 ± 2.51^{a}	59.98 ± 2.42^{a}	60.01 ± 2.56^{a}	60.07 ± 2.62^{a}
T_2	57.79 ± 2.53^{a}	57.89 ± 2.60^{a}	57.96 ± 2.48^{a}	58.04 ± 2.42^{a}	58.17 ± 2.50^{a}
T_3	56.70 ± 2.49^{a}	56.81 ± 2.39^{a}	56.90 ± 2.40^{a}	56.99 ± 2.55^{a}	57.03 ± 2.59^{a}

Mean values not sharing same letter are statistically different ($P < 0.05$)

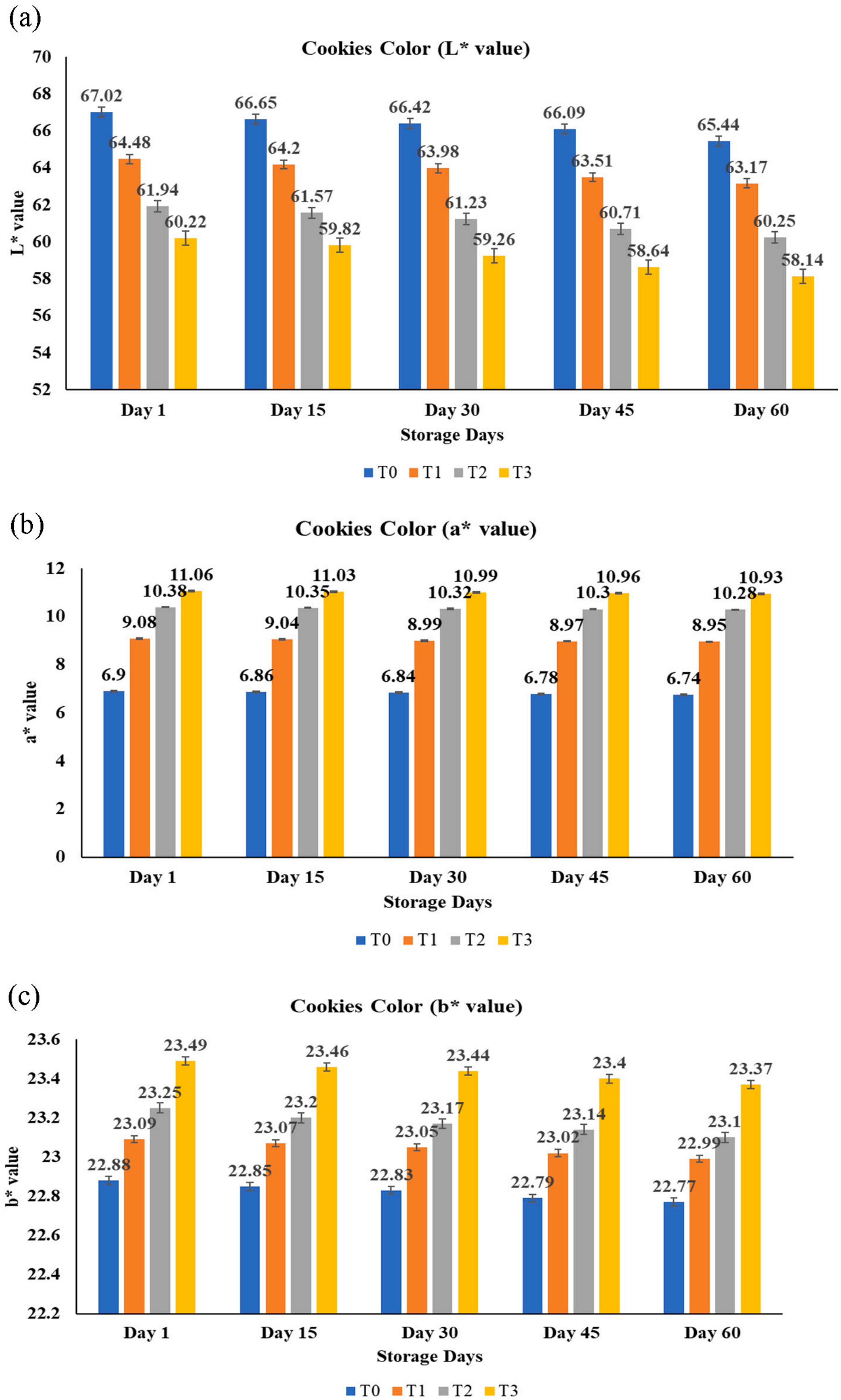

Fig. 2. Graphical representation L*, a* and b* value of color analysis of cookies
(a) Graphical representation of L* value of color analysis of cookies.
(b) Graphical representation of a* value of color analysis of cookies.
(c) Graphical representation of b* value of color analysis of cookies.

unsaturated fatty acids C16:1, C18:1, C18:2, C18:3, C20:1. Table 3 shows the concentration of both saturated and unsaturated fatty acids in oleogel. The oleogel was formulated using two oils with a high concentration of unsaturated fatty acids, resulting in an oleogel with a significant content of unsaturated fatty acids. Oleogel exhibited the highest mean level of linoleic acid, followed by oleic acid, with a minor concentration of other fatty acids. The findings were supported by a study conducted by Mert and Demirkesen (2016) which aimed to create oleogels by combining sunflower oil with carnauba wax and candelilla wax for the purpose of producing cookies and substituting shortening in

Table 5
Calorific value and texture analysis of cookies.

Treatment	Calorific value (Kcal/100 g)				
	Storage days				
	1st day	15th day	3^0th^{day}	45th day	60th day
T_0	455.95 ± 9.44[a]	453.78 ± 7.82[ab]	449.94 ± 9.03[abc]	445.23 ± 8.90[abcd]	441.34 ± 8.72[abcd]
T_1	448.34 ± 8.03[abc]	443.25 ± 8.11[abcd]	439.55 ± 9.42[abcd]	434.98 ± 8.86[abcd]	429.35 ± 7.41[bcd]
T_2	443.53 ± 8.25[abcd]	439.91 ± 8.16[abcd]	435.04 ± 7.80[abcd]	432.38 ± 8.05[abcd]	428.31 ± 9.07[bcd]
T_3	438.74 ± 7.75[abcd]	435.12 ± 7.60[abcd]	431.40 ± 8.14[abcd]	426.64 ± 8.61[cd]	422.31 ± 7.55[d]
Hardness (N)					
T_0	44.96 ± 2.17[a]	44.62 ± 2.22[ab]	44.30 ± 2.15[abc]	44.02 ± 2.19[abcd]	43.38 ± 2.25[abcde]
T_1	38.29 ± 2.05[bcdef]	38.05 ± 2.13[cdef]	37.87 ± 2.08[def]	37.62 ± 1.99[def]	37.33 ± 2.02[ef]
T_2	37.67 ± 1.98[def]	37.23 ± 2.06[ef]	36.95 ± 1.91[f]	36.49 ± 2.01[f]	36.24 ± 2.07[f]
T_3	36.32 ± 2.01[f]	35.88 ± 1.95[f]	35.17 ± 2.12[f]	34.02 ± 2.04[f]	33.74 ± 2.09[f]

Mean values not sharing same letter are statistically different ($P < 0.05$).

the cookies.

3.4. Proximate analysis

The moisture content of cookies showed an increasing pattern. A study conducted by Yılmaz and Öğütcü (2015) investigated the moisture content of cookies throughout a 30-day storage period. The results indicate that the moisture content rises during storage. The cookies from the control treatment T_0 had mean ash content of 0.86 ± 0.06 and then there was an increasing order in the ash content of the cookies formulated with oleogels. The study conducted by Masih et al. (2014) demonstrated a very slight reduction in the ash content of cookies during storage. This effect was observed when linseed oil was utilized as a substitute for shortening in the cookie making process. During the storage, a decrease in the fat content of cookies was noticed. The fat content had the greatest reduction from 23.86 ± 1.13 to 23.15 ± 1.27 for T_0, while the smallest reduction occurred from 29.43 ± 1.29 to 29.03 ± 0.97 for T_3 during the storage period. The research conducted by Srivastava and Mishra (2021) investigated the storage stability of cookies over a period of 245 days. Cookies formulated with microencapsulated vegetable oil powder exhibit minimal reduction in fat content. The decrease in fat content observed during storage may be attributed to the absorption of moisture by the cookies from their surroundings, as well as the breakdown of lipids into other components. The mean values for the crude protein fractions showed a very slight increase in protein content. The highest crude protein content was observed in the cookies for treatment T_3. However, the protein content reduced with time during storage. The slight decrease in protein content could potentially be attributed to the Maillard reaction, which serves as a significant contributor to the degradation of quality in numerous food products. Another possible explanation for the declining protein trend could be attributed to the elevated moisture content seen in cookies. The findings of the protein analyses align with the research conducted by Chandana and Navaratne (2015) in which biscuits were made using sunflower oil and corn oil. Crude fiber has minimal nutritional significance, but it contributes to the overall weight of meals and aids in the regulation of various physiological processes. The reduction in fiber content during storage is attributed to the absorption of moisture from the air. Additionally, the heat treatment method might have various impacts during storage. The research conducted by Srivastava and Mishra (2021) provided evidence to support these findings. The study also evaluated the changes in the fiber content of cookies during a storage period of 245 days. The data from the mean values indicated a decrease in NFE from T_1 to T_3 as the percentage of the oleogel increased. The cookies with 25% oleogel T_1 exhibited the highest NFE content, whereas the cookies with the highest percentage of oleogel (T_3) had a lower NFE content compared to T_1 and T_2. Research conducted by Masih et al. (2014) to evaluate the impact of substituting linseed oil on the physicochemical characteristics of cookies. The NFE of cookies exhibits a declining pattern across different treatments, with the control cookies containing shortening having the highest NFE. Table 4 shows the proximate composition of cookies sample.

3.5. Calorific value, textural analysis, and color analysis

The calorific value of cookies was examined over a period of 2 months at five intervals. During storage, it was noted that the energy value reduced, but the decline rate was not high. It is typically expressed as Kcal/100 g. The treatment T_3 exhibited the highest decrease in energy value, while the treatment T_2 showed the lowest decrease. These findings were supported by the research conducted by Brito et al. (2022) to develop cookies using chitosan-based oleogels. The cookies made using commercial bakery shortening had an energy content of 478.1 Kcal/100 g of cookies, while the oleogel cookies emitted 467.10 Kcal of energy per 100 g of the sample after complete combustion. Textural analysis of cookies was performed by measuring the hardness of cookies. The control treatment T_0 had the highest hardness value of 44.96 ± 2.17 N, whereas treatment T_3 had a somewhat lower hardness value of 36.32 ± 2.01 N, which was the minimum mean value seen. These findings were endorsed by the study done by Yılmaz and Öğütcü (2014) to assess the textural properties of the cookies made with the oleogels of different waxes. The cookies prepared with shortening had a hardness of 47.13 ± 4.8 N while the cookies prepared with wax oleogel showed a hardness of 37.85 ± 3.91 N. Food color is the primary sensory attribute that is crucial in the bakery. The color of a product largely determines consumer perception of its quality, flavor, and reliability. The results indicated that the L* value decreased with an increase in the percentage of oleogel, however the a* and b* values for the cookies increased with an increase in the percentage of oleogel (Fig. 2a, 2b, 2c.). The research conducted by Srivastava and Mishra (2021) provided evidence for these findings. The researchers stored the cookies for a duration of 245 days and examined the color parameters. Table 5 provides a description of the value of cookies in terms of their calorific value and texture analysis.

3.6. Sensory evaluation

The evaluation of the color, flavor, texture, appearance, and overall acceptability of the cookies led to a gradual decline in the scores given by the panelists over a period of 60 days, starting from day 1. The treatment T_2, which involved replacing 50% of margarine with oleogel, was determined to be the most effective treatment. The least effective treatment was T_3, which involved a 75% substitution of oleogel, based on the sensory assessment scores of the cookies. Fig. 3a, 3b, 3c, 3d, 3e displays the results of the sensory evaluation of cookies.

4. Conclusion

The development and application of oleogels represents a significant technological advancement in the field of food science. The goal of this study was to synthesize oleogel using corn oil, sunflower oil and beeswax as oleogelator. The aim was to replace margarine with oleogel in cookie recipe. Physicochemical and antioxidant properties of the oleogel were examined. The analysis showed that the oleogel had viscosity of 0.065 (Pa. s), firmness of 1.33 (N), SFC of 3.33 (%), IV of 129.04 (g I2/100g fat), saponification of 190.50 (mg KOH/g fat), peroxide value of 0.28 (meq O2/kg), TPC of 1.13 (mg GAE/g oil), and antioxidant value of 69.39 (%). Oleogel was utilized to make cookies with more unsaturated fats and less saturated fat. A 100% margarine control treatment was used to make the cookies. The other three treatments, T1, T2, and

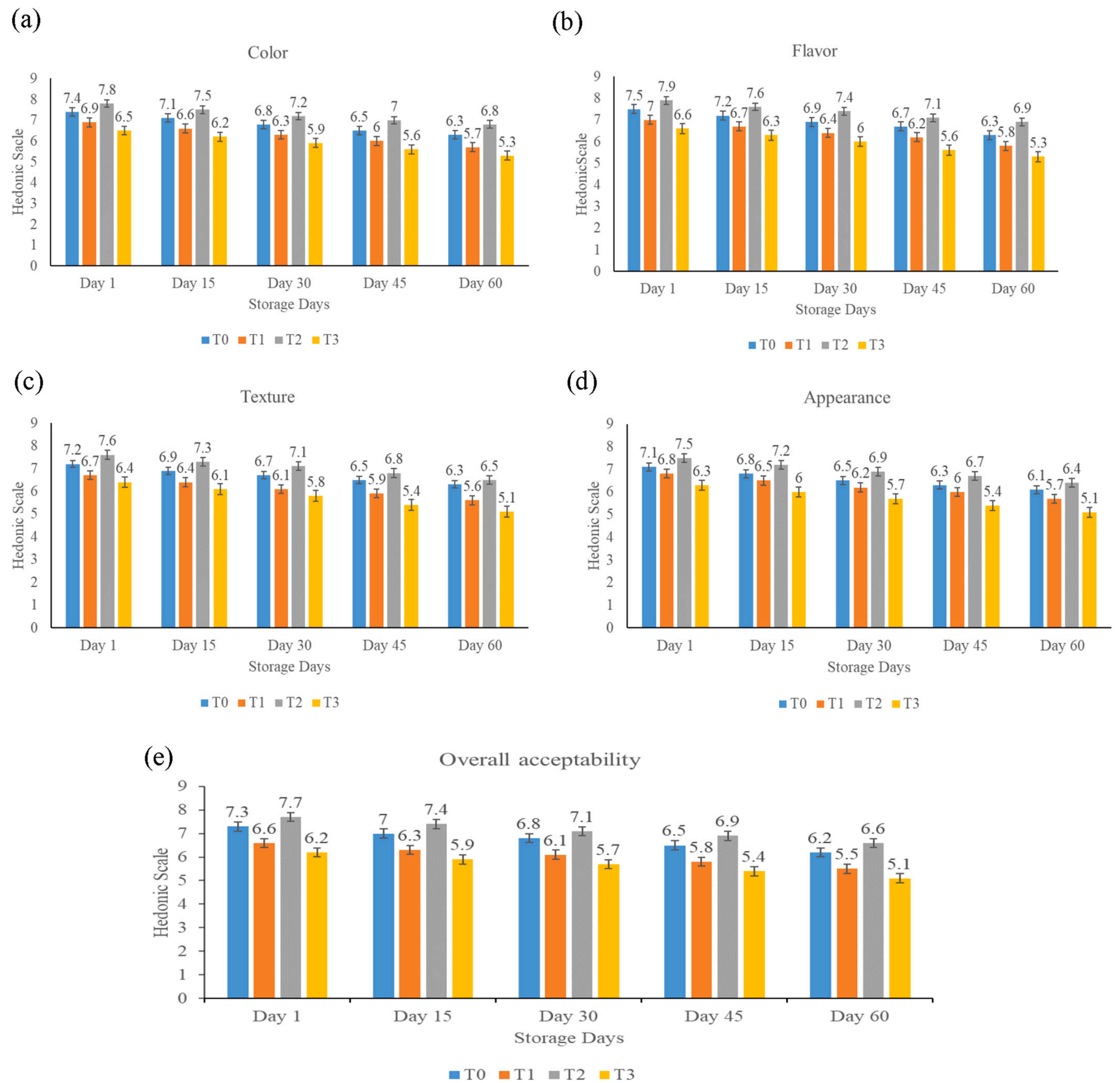

Fig. 3. (a) Graphical representation of color parameter of cookies in sensory evaluation during two months of storage.
(b) Graphical representation of flavor parameter of cookies in sensory evaluation during two months of storage.
(c) Graphical representation of texture parameter of cookies in sensory evaluation during two months of storage.
(d) Graphical representation of appearance parameter of cookies in sensory evaluation during two months of storage.
(d) Graphical representation of overall acceptability parameter of cookies in sensory evaluation during two months of storage.

T3, included different ratios of oleogel and margarine. These treatments were then assessed for proximate analysis. Oleogels can replace trans and hydrogenated fats in food products. This provides healthier cookie alternatives with the same texture, mouthfeel, and stability. Oleogels has distinctive functional characteristics that render them highly appealing for many applications within the food sector The food industry is progressively investigating the utilization of oleogels in diverse food products to enhance their texture, stability, sensory characteristics, and nutritional composition. The unique functional features of oleogels make them suitable for a wide range of food industry applications, allowing for innovation and the creation of healthier and more appealing food products.

Abbreviations

NIFSAT	National Institute of Food Science and Technology
SFC	Solid Fat Content
N	Newton
IV	Iodine Value
SV	Saponification Value
PV	Peroxide Value
DPPH	2,2-diphenyl-1 picrylhydrazyl
TPC	Total Phenolic Content
NFE	Nitrogen Free Extract

CRediT authorship contribution statement

Aqsa Zulfiqar: Conceptualization, Formal analysis, Data curation, Writing – original draft. **Muhammad Asim Shabbir:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Resources, Data curation, Writing – review & editing, Supervision. **Fizza Tahir:** Data curation, Methodology, Writing – review & editing. **Moazzam Rafiq Khan:** Data curation, Methodology, Writing – review & editing. **Waqar Ahmed:** Data curation, Methodology, Formal analysis, Writing – review & editing. **Seydi Yıkmış:** Data curation, Writing – review & editing. **Muhammad Faisal Manzoor:** Data curation, Methodology, Writing – review & editing. **Gholamreza Abdi:** Data curation, Methodology, Writing – review & editing. **Rana Muhammad Aadil:** Conceptualization, Data curation, Writing – original draft, Writing – review & editing, Supervision.

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.

Data availability

Data will be made available on request.

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