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Effect of Oleogelation Temperature on Physicochemical Properties and Stability of Peanut Oil Oleogel (*Arachis hypogaea* L.)

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ABSTRACT

Oleogelation is a method to transform liquid oil into solid fats without altering the fatty acid profile. Compared to hydrogenation, oleogelation requires a relatively simple process and does not produce trans fats. In oleogelation, temperature has a crucial role in affecting the properties of oleogel. Therefore, this study aimed to examine the effect of oleogelation temperature on the physicochemical properties and stability of peanut oleogel. In this study, peanut oil oleogel was formed at 70 °C, 80 °C, and 90 °C using 3% beeswax as oleogelator agent. The best oleogel obtained was stored for 40 days and evaluated for its stability every 10 days followed by testing as a shortening replacer in a cake. The results showed that the higher oleogelation temperature, the greater the hardness and oil binding of oleogel, leading to lower acid and peroxide values. The best oleogelation temperature was obtained at 90 °C with hardness, oil binding capacity, acid, and peroxide values of 0.08±0.01N, 98.31±0.39%, 0.70±0.03 mg KOH/g, and 22.61±0.33 mek O_2/kg, respectively. During 40 days of storage, the hardness and oil binding capacity decreased while the acid, peroxide, and TBA values increased. Additionally, the crystal structure of peanut oil oleogel was affected during storage. The application in cake resulted in lower viscosity of cake batter and a higher yellow index compared to the control (shortening), but the texture profile of cake formulated with oleogel and shorthening (contorl) was not significantly different. This implied that shortening replacement with peanut oil oleogel in baked products was feasible.

Keywords: Beeswax; oleogel; oleogel stability; peanut oil; shortening

INTRODUCTION

Fats are a major component in food products such as butter, margarine, shortening, and spreads, impacting sensory properties including hardness, spreadability, mouthfeel, and texture-related characteristics namely plasticity and elasticity in the final product (Palla et al., 2017). Solid fats contain a higher proportion of saturated fats, while liquid oil has higher levels of unsaturated and polyunsaturated (Kadhum & Shamma, 2017). In various food products such as cakes, sausages, margarine, shortening, confectionery, and others, solid fats play an important role in texture developement. Solid fat or plastic fat can be derived from liquid oil through hydrogenation processes, which entails adding hydrogen atoms to the double bonds of oil or fatty acid carbon chains. The melting point of triglycerides increases with hydrogenation, turning liquid oil into saturated solid fats at room temperature. The purpose is to enhance the plasticity, oxidative stability, and alter the color of oil.

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However, the hydrogenation process has the potential to produce trans fats, which have adverse effects on health. Intake of fats should be limited to a maximum of 10% for saturated and 1% for trans from the total energy requirement (World Health Organization, 2015). This is because both fats can increase LDL cholesterol, a major cause of atherosclerosis and increase the risk of coronary heart disease (World Health Organization, 2015).

Peanut oil contains unsaturated fats reaching up to 80% of unsaturated fatty acids (Wang et al., 2015). Compared to soybean oil, it produces a lower number of triglyceride particles in the LDL subfraction (bad cholesterol) (Kumar et al., 2016), due to the high content of unsaturated fatty acids. Peanut oil has the potential to be used in various food products such as cakes, shortening, confectionery, and others but the application is limited by its consistency, which is liquid at room temperature. To overcome this challenge, the consistency can be modified through oleogelation to become solid at room temperature with the addition of oleogelator.

Oleogelation, currently receiving significant attention as an alternative to hydrogenation. It produces oleogel that can replace solid fats which rich in saturated fatty acids with healthier alternatives through the immobilization process of liquid vegetable oil within a three-dimensional network formed by oleogelator (Scharfe & Flöter, 2020). Through the process, solid fats with desired functional properties are obtained without causing significant changes in the texture of food products (Temkov & Muresan, 2021). Common oleogelators used for oil gelling include wax, monoglycerides, alcohol or fatty acid esters, phospholipids, and phytosterols (Pérez-Monterroza et al., 2014). The use of beeswax has great potential as a structuring agent due to the food-grade nature, accessibility, affordability, and ability to gel liquid oil at relatively low concentrations, producing oleogel with physical characteristics resembling solid fats (Tavernier et al., 2017).

Oleogel needs to possess good physicochemical properties to produce food products with the desired characteristics, which are influenced by gelation temperature, type and concentration of oleogelator, as well as oil type (Aliasl khiabani et al., 2020; Alvarez-Ramirez et al., 2020; Davidovich-Pinhas et al., 2015). Thakur et al. (2022) and Davidovich-Pinhas (2015) investigated the effect of gelation temperature on the properties of canola oil and soybean oil oleogel made with candelilla wax and ethyl cellulose. The results showed that gelation temperature affected the characteristics of canola and soybean oil oleogel. Studies on the effect of gelation temperature on the formation of peanut oil oleogel stabilized by beeswax and its oxidative stability during storage are still limited. Therefore, this study aimed to investigate the influence of gelation temperature and storage on the physical, chemical, and oxidative stability properties of peanut oil oleogel gelated using beeswax oleogelator. In addition, the effect of shortening replacement with peanut oil oloegel in cakes was also evaluated.

METHODS

Materials

The study used DKP Peanut Oil (Galarasa F&B, Sidoarjo) and food-grade beeswax from Sarang Lebah Hutan *Apis dorsata* (babybees, Tangerang). Additionally, ingredients such as wheat flour (Segitiga Biru), shortening, sugar, salt, baking powder (Koepoe Koepoe), cream of tartar (Koepoe Koepoe), eggs, and liquid milk obtained from a local supermarket were used for baking purposes.

The chemicals used for analysis included 96% ethanol, glacial acetic acid, PP indicator, chloroform, sodium tetraborate, BCG-MR indicator, potassium iodide, 0.1 N KOH, sodium thiosulfate (Merck, Germany), starch indicator, KIO3, oxalic acid, 37% HCl (Mallinckrodt, USA), TBA reagent, Hanus reagent, isooctane (Merck, Germany), anisidine reagent, and distilled water.

Making Peanut Oil Oleogel

Peanut oil oleogel was prepared using the method developed by Alvarez-Ramirez et al. (2020) and Lim et al. (2017) with slight modifications. Beeswax (3%) and peanut oil were weighed using an analytical balance (Fujitsu FS AR120) in a glass beaker, then a 4 cm *magnetic bar* was inserted. The mixture was heated at temperatures of 70 °C, 80 °C, and 90 °C using a *magnetic stirrer* (Heidolph, MR Hei Standart 505 20000 00, Germany) at 250 rpm for 5 minutes. The selection of gelation temperature was based on the melting point of beeswax oleogelator, namely 65 °C, hence, the temperatures selected were higher. The samples were poured into jars and cooled to room temperature, then stored at approximately 4°C for 24 hours to allow gel formation. For oxidative stability evaluation, peanut oil oleogel was stored for 40 days, with observation points at 0, 10, 20, 30, and 40 days.

Application of Peanut Oil Oleogel in Cake Formulation

Peanut oil oleogel with the best preparation temperature based on physical and chemical parameters was applied in cake formulation as a replacer for

Table 1. Cake formulations with and without peanut oil oleogel

Material	Material composition (g)	
	Shortening	Oleogel
Flour	70	70
Sugar	60	60
Salt	1	1
Baking powder	1.5	1.5
Egg yolk	56	53.5
Liquid milk	62	62
Shortening	25	25
Egg whites	100	100
Cream of Tartar	1	1

shortening. The formulation followed the study by Aliasl khiabani et al. (2020) with slight modifications. The formula can be seen in Table 1.

A portion of sugar, egg yolks, liquid milk, and melted shortening oleogel using a saucepan and stove (Rinnai RI 512 MS) were stirred until evenly mixed. Afterwards, the mixture of wheat flour, salt, and baking powder was sieved and poured into the batter gradually while stirring. In another bowl, egg whites and cream of tartar were beaten using a hand mixer (Maspion MT-1150) followed by gradual addition of the remaining sugar until the egg whites formed soft peaks (approximately three minutes). A small portion of the egg whites was subsequently added into the batter and stirred until evenly mixed. The batter was then poured into the remaining egg whites and stirred using a spatula. Subsequently, the sample was poured into a 16 cm diameter tray and baked in an oven (Fujimak) at 160°C for 40 minutes. The resulting cake was sliced crosswise, photographed, and visually observed for the macrostructure, focusing on the uniformity of the pores.

Chemical Parameters

The chemical properties and oxidative parameters of peanut oil and oleogel were evaluated by determining the Acid (AOCS, 2009, Cd 3d-63 method), Peroxide (AOCS, 2003, Cd 8-53 method), Anisidine (AOCS, 2014, Cd 18-90 method), Saponification (AOCS, 2013, Cd 3-25 method), TBA (Tarladgis et al., 1960), and Iodine Value (AOAC, 2000, Cd 920.158 method).

Fatty Acid Composition Analysis

The gas chromatography method based on AOAC Official Methods 969.33 and 963.22 (AOAC, 2002) was used to determine the fatty acid composition. Initially, 10 mL of concentrated HCl was added to 5-10 g of the sample. This was followed by hydrolysis through heating by using a water bath at 80 °C for 3 hours. The sample was cooled, extracted with 25 mL of a mixture of diethyl ether and petroleum ether (1:1), vortexed, then allowed to settle until precipitation occurred and the upper layer was extracted as oil to be evaporated in a water bath using N2 gas. The next step was methylation by adding a solution of sodium methoxide to 0.5 mL of the sample and heating at 60 °C for 5-10 minutes while homogenizing. The sample was then cooled to room temperature, and 2 mL of boron trifluoride methanol solution was added followed by cooling. Afterwards, the solution was heated for 5-10 minutes and cooled. Subsequently, the sample was further extracted with 1 mL of heptane and 1 mL of saturated NaCl solution. The upper layer in the extraction process was separated and used for injection. About 1 μL of the sample was used for injection into the Gas Chromatography (Agilent 7890B).

Hardness Analysis

The analysis of peanut oil oleogel hardness was conducted using a Universal Testing Machine (Zwick / Z0.5). The sample in a glass jar was placed beneath the probe with a diameter of 12.7 mm, then compressed with a pre-load of 0.01 N, a pre-load speed of 300 mm/minute, and a test speed of 10 mm/minute. The test results included the maximum force in Newton and the duration of compression causing deformation of peanut oil oleogel.

Oil Binding Capacity (OBC) Analysis

OBC was determined using the centrifugation method following the study by Winkler Moser et al. (2019), with slight modifications. 10 g of oleogel was placed into a centrifuge tube and centrifuged (Thermo Scientific Sorvall ST 8R, USA) at 4500 rpm, 25 °C, for 30 minutes. All released liquid oil was removed from the tube using a dropper pipette and filter paper, then the remaining oleogel in the centrifuge tube was weighed and calculated using Equation 1.

$$\text{Oil binding capacity} = 100\% - \left(\frac{\text{m1}-\text{m2}}{\text{m}} \times 100\%\right) \quad (1)$$

Description: m1 = weight of tube + oleogel before centrifugation (g), m2 = weight of tube+oleogel after centrifugation and removal of released oil (g), and m = sample weight (g).

Viscosity Analysis

The viscosity analysis of the cake batter was conducted using a viscometer (Brookfield Viscometer DV2T). Sample was poured into a cylindrical container up to the marked line, then spindle (number 62 for oil and 64 for cake batter) was attached to the viscometer. The sample was placed beneath the spindle, and the viscometer was adjusted until the spindle was submerged in the sample up to the marked line. The measurement was performed at 60 rpm for 30 seconds and at room temperature.

Microstructural Observations

Observations of the structure of peanut oil oleogel on days 0 and 40 were carried out using a polarized light microscope (OMAX, USA) connected to the Dino-Lite AM7023 (R4) camera application on a computer at 10x magnification.

Cake Color Analysis

The color parameters of the cake (L*, a*, and b*) were analyzed using a chromameter (Konica Minolta Chroma Meter CR-400, Japan). Color analysis was carried out following the study of Alvarez-Ramirez et al. (2020) with a cake sample placed in a small petri dish and then positioned on top of the chromameter lens. The value was measured by pressing the "Measure Enter" button on the tool until a flash of light appeared. The results of the analysis included L* (light/dark), a* (reddish/greenish), and b* (yellowish/bluish) values. The total color difference between cake samples and controls was calculated using Equation 2.

$$\Delta E^* = \sqrt{(L^* - Lk^*)^{\,2} + (a^* - ak^*)^{\,2} + (b^* - bk^*)^{\,2}} \qquad (2)$$

Description: ΔE* = color difference between sample and control; L*, a*, b* = color of cake sample (peanut oil oleogel); and L_k*, a_k*, b_k* = control colors (*shortening*).

Cake Texture Profile Analysis

The texture profile analysis of the cake was conducted using *Texture Analyzer* (TA1 Lloyd) following the study by Aliasl khiabani et al. (2020) with slight modifications. The analysis was performed with Cake samples cut into 2 x 2 x 2 cm cubes and compressed at room temperature using a cylindrical probe with a diameter of 3.5 cm. The cake samples were compressed to 50% of the original height at a speed of 150 mm/second, with a wait time of 0.5 seconds, a preload/stress of 1 N, and a preload/stress speed of 300 mm/minute. Subsequently, the Nexygen Plus software was used to determine the texture parameters of the cake, such as hardness (N), cohesiveness, and springiness (mm).

Statistic Analysis

This study used a non-factorial Completely Randomized Design with three replications. All analyses were performed using SPSS 26 software with two-way ANOVA and one-way ANOVA, followed by a post-hoc Tukey HSD test, which had a significance level of 95%. One-way ANOVA was used to determine the effect of oleogelation temperature on the hardness, OBC, acid value, and peroxide value of peanut oil oleogel. Meanwhile, Two-Way ANOVA was used to investigate the influence of storage and sample type on the predetermined parameters as well as to compare peanut oil oleogel samples during storage with the control (peanut oil). The Independent Sample T-Test, which had a significance level of 95%, was used to compare cake samples with oleogel and control (shortening).

RESULTS AND DISCUSSION

Characterization of Peanut Oil

The acid, iodine, and anisidine value of peanut oil (Table 2) fell within the range of values reported in the literature, ,i.e.,: ≤ 4 mg KOH/g, 86–107 g I2/100 g (Branson et al., 2004), and 1.03–4.77 meq/kg (Roshni, 2019) respectively. However, the saponification value was lower compared to the result by Branson et al. (2004), with values of 187-196 mg KOH/g.

Based on Table 3, DKP peanut oil consisted of 79.03% unsaturated and 21.04% saturated fatty acids. The unsaturated fatty acids were predominantly linoleic, linolenic, and oleic acids, while the saturated was predominantly palmitic acid. The results were consistent with Wang et al. (2015), stating that peanut oil consisted of approximately 80% unsaturated fatty acids and 20% saturated. The presence of unsaturated fatty acids and the high iodine value shows that peanut oil has low oxidative stability. Therefore, there is a need to evaluate the oxidative stability of peanut oil oleogel during storage.

Table 2. Characterization results of peanut oil with the DKP brand

Parameter	Value
Acid value (mg KOH/g)	0.59±0.04
Peroxide value (m_{ek} O_2/kg)	22.14±0.01
Iodine value (g I_2/100 g)	86.26±0.52
Saponification rate (mg KOH/g)	164.43±0.72
Anisidine value (m_{ek}/kg)	3.37±0.36
Viscosity (cP)	52.40±0.93

Table 3. Fatty acids composition of peanut oil

Types of fatty acids	Concentration (% relative)
Palmitic acid	19.82
Stearic acid	1.07
Docosanoic acid	0.15
Total saturated fatty acids	21.04
Palmitoleic acid	0.22
Cis-9 oleic acid+trans-9 elaidic acid	6.35
Linoleic acid + linolelaidic acid	7.8
Gamma-linoleic acid	43.72
Cis-11-eicosenoic acid	2.96
Linolenic acid	8.97
Cis-11-14-eicosadienoic acid	1.54
Erucic acid	3.92
Cis-5-5-8-11-14-eicosatetraenoic acid	0.19
Cis-13-16-docosadienoic acid	1.90
Cis-5-8-11-14-17-eicosapentaenoic acid	0.20
Nervonic acid	0.82
Cis-4-7-10-13-16-19-docosahexaenoic acid	0.35
Total unsaturated fatty acids	79.03

Effect of Temperature on the Physical and Chemical Properties of Peanut Oil Olegel

Hardness

Replacing saturated solid fats with gelled liquid oil has a critical impact on the mouthfeel and texture (Tavernier et al., 2017). One of the most important texture properties in solid fats is hardness, which refers to the force required for deformation or shape change (Meilgaard et al., 2016). Data in Table 4 showed that the hardness of peanut oil oleogel increased with higher temperature, and the highest value of 0.08±0.01N was obtained at 90 °C. Based on the statistical analysis results, the hardness at 90 °C differed significantly from the value at 70 °C and 80 °C, but the value obtained at 70 °C did not differ significantly from 80 °C (Table 4). Palla et al., (2017) reported that the hardness of oleogel increased with higher oleogelation temperatures with the highest hardness s was obtained at the highest temperature. The preparation of oleogel with high heating temperature and agitation speed can form new hydrogen bonds, which play a crucial role in stabilizing the gel network with oil-gelator distribution after cooling. High heat can add energy to oleogel system, thereby producing a more structured product with better mechanical properties (Kouzounis et al., 2017).

Oil Binding Capacity (OBC)

OBC shows the relative ability of oleogel to bind liquid oil within the three-dimensional network of oleogel (Yilmaz & Öğütcü, 2015). The analysis showed that this parameter increased with the higher oleogelation temperature, with the highest value obtained at 90 °C (Table 4). Peanut oil oleogel with beeswax as the gelator showed the best OBC, trapping more than 90% of oil within the three-dimensional network. Based on the statistical analysis results, OBC of oleogel at 70 °C differed significantly from 80 °C and 90 °C, but the values obtained at 80 °C and 90 °C did not differ significantly.

As shown by the results, OBC of oleogel was directly proportional to the hardness. An increase in oleogelation temperature led to higher oleogel hardness and heightened ability to bind oil within the three-dimensional network, resulting in greater OBC. On the other hand, lower heating temperature yielded relatively low OBC due to the formation of irregular crystal networks with varying sizes and shapes (Palla et al., 2017). The ability to bind oil within the gel network structure depends on the distribution, surface absorption, surface roughness and morphology, of particles in a system. Fayaz et al. (2020) showed that oleogelators

Table 4. Hardness, oil binding capacity, acid value, and peroxide value of peanut oil oleogel made at different oleogelation temperature

Oleogelation temperature (°C)	Hardness (N)	Oil binding capacity (%)	Acid value (mg KOH/g)	Peroxide value (m_{ek} O_2/kg)
70	0.05±0.00^a	93.12±0.77^a	0.69±0.01^a	24.16±0.19^b
80	0.06±0.01^a	97.73±0.21^b	0.76±0.01^b	22.72±0.69^a
90	0.08±0.01^b	98.31±0.39^b	0.70±0.03^a	22.61±0.33^a

Description: Data with different lowercase notations in one column shows significant differences according to the *Tukey HSD* test (p<0,05) forming crystals with needle-like morphology such as stearic acid, octadecanol, sunflower wax, and beeswax produced networks with higher OBC. This was because the surface area of the crystals was greater compared to those with spherical morphology.

OBC was also influenced by the melting point of the oleogelator, with higher melting temperature increasing the number of hydrogen bonds. This phenomenon created networks with better physical properties but with lower OBC (Davidovich-Pinhas et al., 2015). Based on the results, OBC increased with higher heating temperature above 90°C. Yılmaz & Öğütcü (2014) reported that camellia oil oleogel with beeswax had OBC of over 99%. Differences in study results may be due to variations in the types of oil used and the source of beeswax oleogelators.

Acid Value

Based on the analysis results, the acid value of peanut oil oleogel increased at oleogelation temperature of 80 °C and then decreased at 90 °C (Table 4). Moreover, the acid value at 80 °C differed significantly from the values at 70 °C and 90 °C, which was nearly the same (0.69-0.70 mg KOH/g sample), as shown in Table 4. The higher acid value at 80°C may be due to the hydrolysis process and the result of increased heating temperature. Water and steam at high temperature hydrolyze triglycerides, thereby producing monoglycerides, diglycerides, glycerol, and free fatty acids.

Peroxide Value

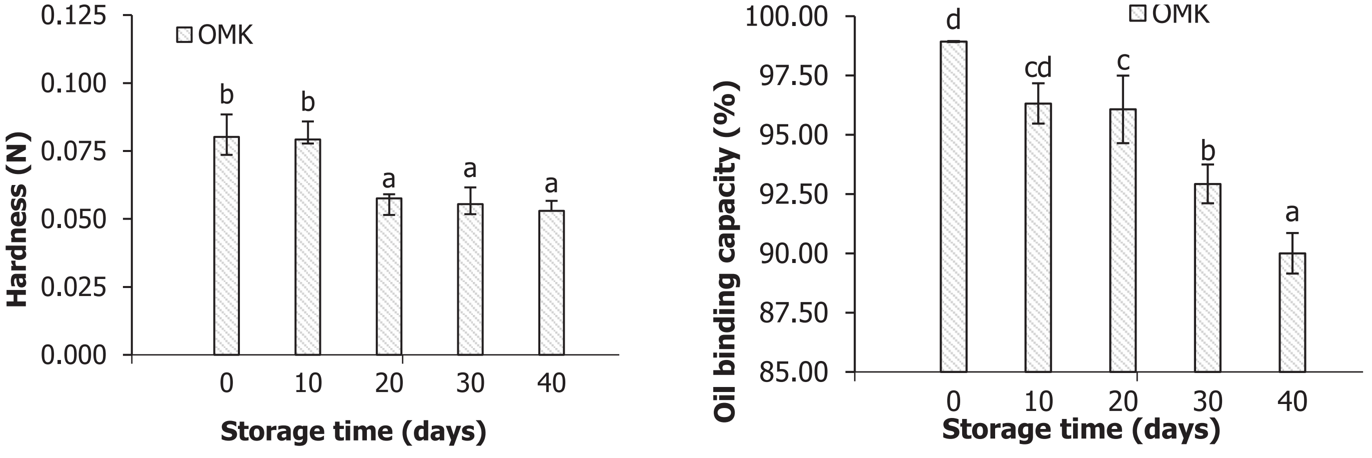
The analysis results showed that increasing oleogel formation temperature led to lower peroxide value. The lowest peroxide value was obtained at the highest temperature of 90 °C, namely 22.61±0.33 meq O_2/kg (Table 4), and was nearly the same as that of the initial peanut oil characterized (Table 2). Based on the statistical analysis results, the peroxide value of oleogel made at 70 °C differed significantly from the values obtained at 80 °C and 90 °C, which both had no significant difference. Furthermore, the peroxide value correlated with the hardness of oleogel. A decrease in the peroxide value was observed with heightened hardness of oleogel structure as oleogelation temperature increased. This was primarily due to the greater oxidative resistance in harder oleogel. Immobilization and migration of oil through the solid oleogel system are effective in slowing down oil oxidation (Lim et al., 2017).

Stability of Peanut Oil Oleogel during Storage

The physical characteristics of oleogel produced influence the properties of food products and consumer acceptance. The best-treated peanut oil oleogel was obtained at oleogelation temperature of 90°C, indicated by the highest values of hardness and OBC, as well as the lowest values of acidity and peroxide value, depicting good oxidative stability.

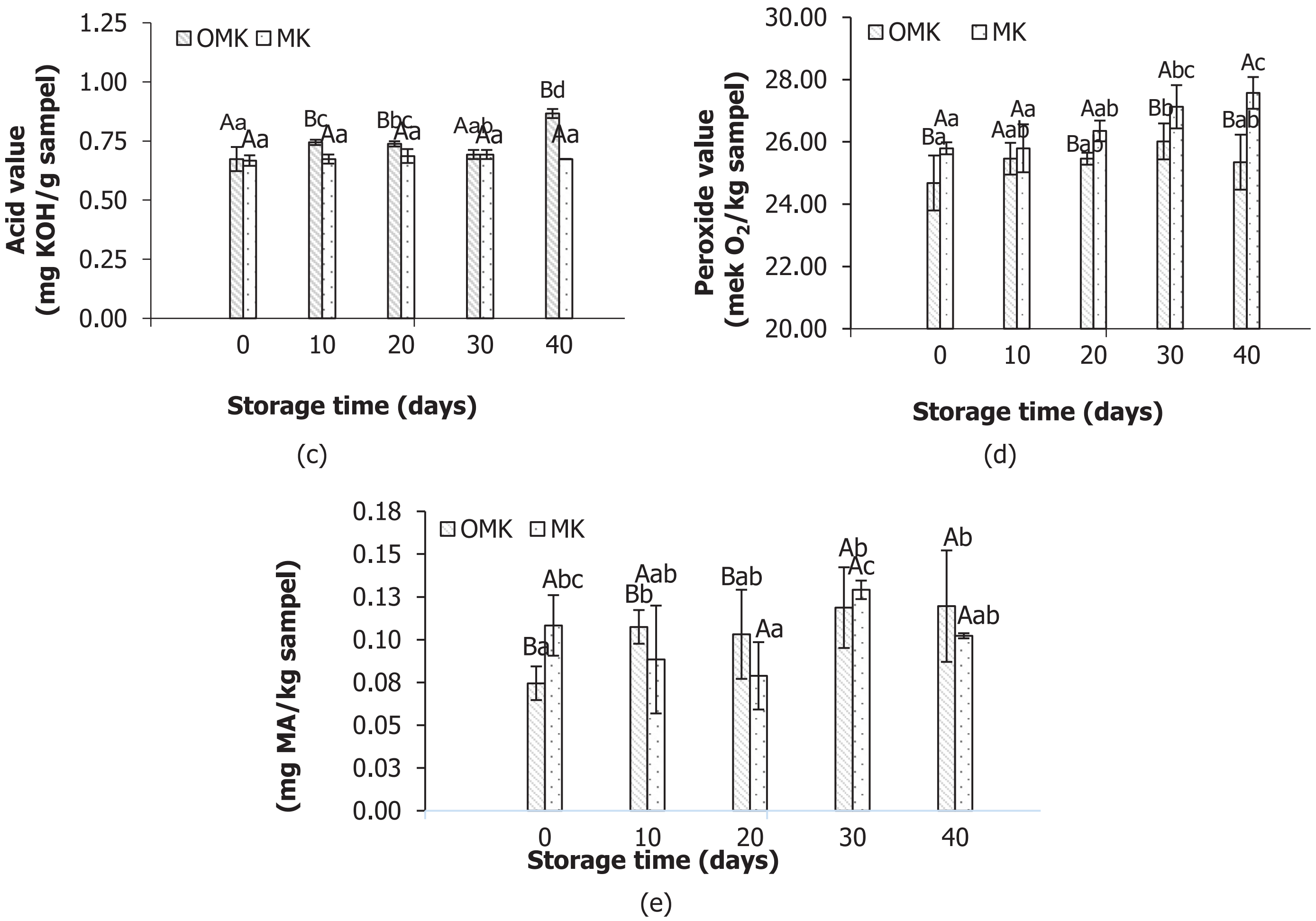
Hardness

The hardness of peanut oil oleogel tended to decrease as the storage time increased (Figure 2a). The highest value was obtained on day 0 of storage (fresh oleogel), while the lowest was recorded on day 40. Based on the statistical analysis results, the hardness of oleogel on day 0 was significantly different from days 20, 30, and 40, which had no significant difference. Papadaki et al. (2020) investigated olive oil oleogel with wax esters as oleogelators derived from soybean fatty acid distillate. The results showed a significant decrease in the hardness of olive oil oleogel during 30 days of storage, but stability was observed on days 10, 20, and 30. The decline in hardness value may be attributed to the formation of larger crystals, resulting in less effective surface area and fewer interactions among particles (O’Brien, 2008).



(a)

(b)



Description: Different lowercase notations on the same color bar show significantly different data according to the Tukey HSD test (p<0,05). Different capital letter notations show that the data between the two samples on the same storage day are significantly different according to the Independent Sample T-Test (p<0,05).

Figure 2. Hardness (a), oil binding capacity (b), acid value (c), peroxide value (d), and TBA value (e) of peanut oil oleogel during 40 days of storage

Oil Binding Capacity (OBC)

The analysis results showed that OBC of peanut oil oleogel decreased with increasing storage time. The highest value was observed on day 0 of storage, while the lowest was found on day 40 (Figure 2b). There was a significant difference between the OBC of oleogel stored on day 0 compared to days 20, 30, and 40 (p<0.05). OBC on day 0 did not significantly differ from day 10, while day 10 had no significant difference from day 20.

Observation of Oleogel Microstructure

During the cooling process of oleogel, crystals from the wax gelator began to form a three-dimensional network depending on the morphology and polymorphism of the crystal particles, which could be visualized in various ways. Based on the observations, the crystal structure produced with 3% *beeswax* gelator had small needle-like crystals that were interconnected and evenly distributed, leading to a three-dimensional network capable of trapping oil (Figure 1a). These observations were consistent with Yilmaz & Ogutcu (2014), stating that the crystal structure of palm oil oleogel with *beeswax* gelator resembled needles. This could be due to the presence of wax esters in *beeswax*, which could reach 60-70% (Fayaz et al., 2020).

During storage, the crystal structure of oleogel experienced changes, becoming slightly longer, larger, and denser compared to day 0 (Figure 1b). This was because larger crystals were formed due to less effective surface area and fewer interactions between particles during storage, leading to a decrease in oleogel *hardness* (O'Brien, 2008). As stated by Fayaz et al. (2020),

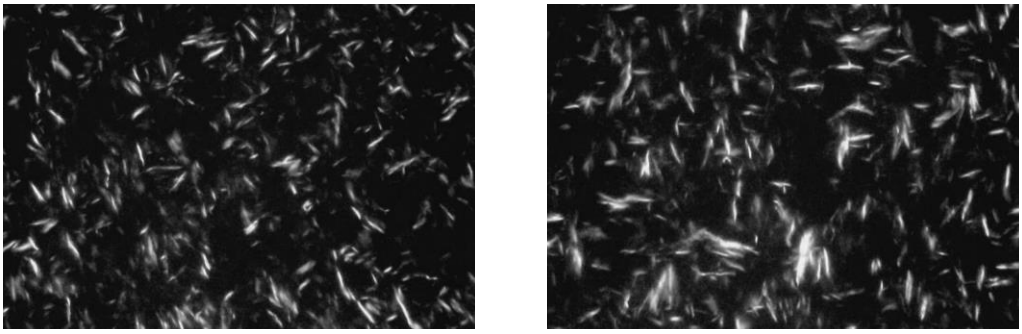

(a) (b)

Figure 1. Microstructure of peanut oil oleogel using beeswax 3% which had undergone storage for (a) 0 days and (b) 40 days

sunflower oil oleogel with γ-oryzanol and β-sitosterol gelators failed to show crystal formation on the first day of storage. New crystals was observed after 15 days of storage, primarily because molecular crystallization did not aggregate in the tissue and remained soluble in oil. Meanwhile, *sunflower oil* oleogel with *beeswax* gelator showed no significant microstructural changes.

Acid Value

Free fatty acids are products of lipid hydrolysis, and the quantity is reflected by the acid value, which is influenced by the sample, storage, and the interaction of both. Based on the results, the acid value of peanut oil oleogel increased with prolonged storage, and the highest value of 0.87±0.02 mg KOH/g sample was obtained on day 40 of storage (Figure 2c). The acid value on day 0 was significantly different from days 10, 20, and 40, but not significantly different from day 30. For the control, the value remained almost the same throughout the storage period, as shown by statistically insignificant differences. This was presumably because the samples were stored at a low temperature (4 °C) and in tightly sealed containers, minimizing the occurrence of hydrolysis.

The acid values of peanut oil oleogel on days 10, 20, and 40 were significantly different and higher than the control (Figure 2c). This was consistent with the study by Szymańska et al. (2021), stating that oleogel made from rapeseed and linseed oil with candelilla wax gelator (3% w/w) resulted in three times higher acid values compared to the initial mixture of only rapeseed and linseed oil. The higher acid values in oleogel compared to peanut oil may be due to the presence of structuring agent. Moghtadaei et al. (2018) reported a significant increase in the acid value of sesame oil oleogel with increasing beeswax concentration. Beeswax oleogelators are composed of straight-chain acids up to 36 carbons long and C18 hydroxyl acids such as esters, diesters, and triesters, which have relatively high levels of free fatty acids. These properties were responsible for the higher acid value in peanut oil oleogel compared to the sample without a structuring agent (Moghtadaei et al., 2018). However, the acid values of peanut oil and oleogel were still below 2%. The United States Department of Agriculture states that oil with acid values above 2% is not suitable for consumption.

Peroxide Value

During lipid oxidation, hydroperoxides as primary oxidation products decompose into secondary forms including volatile organic compounds namely aldehydes, ketones, alkanes, alcohols, esters, and epoxides, which can cause unpleasant flavors and affect the taste of food products (Zhang et al., 2020). The peroxide number reflects the amount of primary oxidation products which may exceed acceptable limits during storage and the effect of wax on oxidation becomes more apparent after longer storage periods. Based on the statistical analysis results, sample, storage, and the interaction affected the peroxide value (Figure 2d). Along with increasing storage time, the peroxide value of oleogel increased until day 30, then decreased on day 40. Meanwhile, in peanut oil without oleogelation, an increase was also observed during storage, reaching the highest value on day 40 (Figure 2d).

The peroxide value of peanut oil oleogel was lower compared to the control, showing significant differences on days 0, 20, 30, and 40 (Figure 2d). Similar results have been reported in a previous study by (Lim et al., 2017). Changes in peroxide value during storage reflect the oxidative stability of products containing oil. The oxidation in oleogel was slower than that in peanut oil due to the lipid immobilization.

Beeswax contains more than 50% esters, 14% hydrocarbons, and 12% free fatty acids (Hepburn et al., 2014). The presence of free fatty acids is an initial indicator of oil or fat damage due to hydrolysis, which is more prone to oxidation compared to the ester form. The use of beeswax as oleogelator may increase the peroxide value during storage due to the ability to act as a pro-oxidant, referring to compounds that initiate or accelerate lipid oxidation. In the subsequent oxidation stage, the rate of oxidation and the peroxide value of oil were higher than those of oleogel (Frolova et al., 2021). The decrease observed in peanut oil oleogel on day 40 may be due to further oxidation of peroxides, resulting in secondary products undetected. During storage, the peroxide value of peanut oil oleogel samples remained below 100 meq O_2/kg. According to a previous study, oxidized oil with a peroxide value above 100 meq O_2/kg might be neurotoxic (Gotoh et al., 2006).

TBA Value

TBA value (thiobarbituric acid value) determines the amount of secondary lipid oxidation products. Based on the statistical analysis results, storage and interaction between samples and storage affected the parameter. During storage, the TBA value of peanut oil oleogel increased with longer storage time, but there were no significant differences on day 10, 20, 30, and 40 (Figure 2e). However, day 0 had a significantly different value from day 10, 30, and 40. The highest TBA value of peanut oil oleogel was observed on day 30 (0.12±0.02 mg MDA/kg sample) and 40 (0.12±0.03 mg MDA/kg sample). In peanut oil, the TBA value remained stable until day 20, then increased on day 30 and decreased on day 40. Figure 2e shows significant differences between peanut oil oleogel samples and control on days 0, 10, and 20. This might be due to the breakdown of malondialdehyde into several other derivative products. Secondary oxidation products are reactive compounds because the chemical structure can react independently or with other compounds, forming tertiary volatile compounds, such as methyl ketones from 2,4-alkadienal (Grebenteuch et al., 2021). TBA values above 1-2 mg MA/kg cause off-flavors in oil due to oxidation products (Guizani et al., 2014). In this study, peanut oil oleogel was found to have TBA values significantly below 1 mg MA/kg.

Application of Peanut Oil Oleogel in Cake

Viscosity of the Cake Batter

The amount of air incorporated into cake batter depends on the technique and speed of mixing, efficiency in retaining air bubbles, and viscosity (Fiszman et al., 2013). Viscosity shows the thickness or resistance to flow of a fluid, and during baking, the velocity gradient in the batter induces convection currents at certain times, depending on the viscosity. According to a previous study, lower-viscosity cake batter produced better heat convection during baking (Fiszman et al., 2013), underscoring the need to measure this parameter. Based on the results, samples formulated using oleogel produced cake batter with lower viscosity values than the control (Table 5). This suggested that cake batter produced using peanut oil oleogel had lower consistency than that produced using shortening. The viscosity of cake batter formulated with oleogel was significantly lower than that with shortening ($p<0.05$). The results were in line with the finding of with Lim et al. (2017), who reported the effect of replacing shortening with oleogel in muffins. Based on the results, muffin batter using grape seed oil-candelilla wax oleogel had lower batter viscosity and elasticity compared to the use of shortening. Oh et al. (2017) also stated that the control

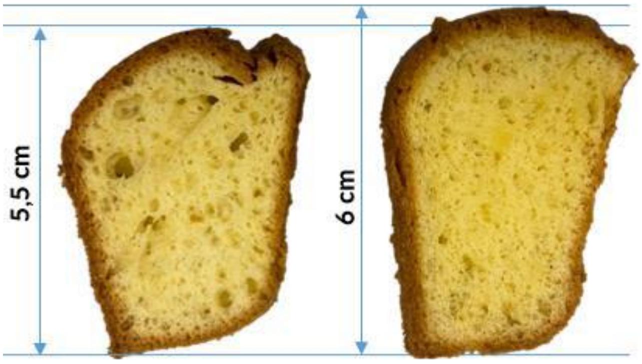
Table 5. Characteristics of cakes using oleogel and *shortening*

Characteristics	Peanut oil oleogel	Shortening
Viscosity (cP)	23.70±2.62^a	29.20±2.03^b
Color		
L^*	70.15±0.59^a	70.15±0.54^a
a^*	-5.74±0.13^a	-6.07±0.07^b
b^*	29.40±0.20^a	27.48±0.82^b
Texture profile		
Hardness (N)	4.30±0.26^a	4.20±0.18^a
Cohesiveness	0.75±0.01^a	0.72±0.05^a
Springiness index	0.77±0.01^a	0.76±0.02^a

Description: Different lowercase notations in one line show significant differences according to the Independent Sample T-Test ($p<0.05$)

cake batter made with shortening had a higher viscosity than that with oleogel. In that study, sunflower oil-based oleogel was used with rice bran wax, beeswax, and candelilla wax as oleogelators. The viscosity value of the cake batter made using oleogel was lower due to the reduced solid fat content at room temperature compared to that made with shortening (Lim et al., 2017).

Visual Observation of The Cake



(a) (b)

Figure 3. Appearance of the cake made with *shortening* (a) and peanut oil oleogel (b)

Cakes formulated using oleogel showed higher expansion and more uniform pore size than the control (Figure 3b). This result was in agreement with the study by Alvarez-Ramirez et al. (2020), stating that adding candelilla wax to canola oil oleogel reduced the consistency of cake batter and enhanced uniform air bubbles in the product. Shortening plays a crucial role in baking, lubricating gluten particles, and providing aeration to the cake, which results in a softer texture (Habi Mat Dian, 2018). The type of fat also affects the internal and external quality of the cake. Based on the results, peanut oil oleogel can replace shortening as it produces cakes that are softer, more expanded, and have more uniform pore size.

Cake Color

The color analysis of the cake comprises L* showing brightness level, a* denoting redness (+) or greenness (-), as well as b* representing yellowness (+) or blueness (-). Cake samples formulated using oleogel and shortening had the same brightness level, as indicated by the L* value, with no statistically significant difference (Table 5). Moreover, the results showed a negative value for parameter a* and a positive value for parameter b*, implying a bright yellow color. Cake samples formulated using peanut oil oleogel had higher values of a* and b* than those produced with shortening. Based on the statistical analysis results, a* and b* values between the two cake samples differed significantly. The natural yellow color from wax caused an increase in yellow color in oleogel samples (Moghtadaei et al., 2018), affecting the final color of food products. Furthermore, the ΔE value was used to illustrate the overall color difference between the peanut oil oleogel sample and the control formulated using shortening. Based on calculations using formula 8, the ΔE value obtained was 1.95, showing that cake formulated using peanut oil oleogel and shortening had little different colors.

Cake Texture Profile

Hardness refers to the force required for shape change or deformation in food products (Meilgaard et al., 2016), while cohesiveness shows the level of sample deformation, which is the strength of bonds composing the material structure (Meilgaard et al., 2016). Additionally, springiness shows elasticity, which is the ability to restore the texture of the cake between the first and second bites in the double compression test. Based on the analysis results of hardness, cohesiveness, and springiness, cake samples formulated using peanut oil oleogel did not differ significantly from those produced with shortening ($p>0.05$) (Table 5). As stated by Demirkesen & Mert (2019), the hardness value of cakes increased after replacing shortening with sunflower seed oil oleogel using 10% beeswax (b/b) as a gelling agent. Aliasl khiabani et al. (2020) also mentioned that the springiness and cohesiveness values of cakes differed significantly following the replacement of 50% shortening with oleogel at a concentration of 6%. In this study, replacing shortening with peanut oil oleogel had no significant effect on the texture profile of the analyzed cake. This may be due to the low concentration of oleogelator used in the preparation (3% b/b) compared to previous studies, that used higher concentrations, namely 6 - 10% w/w (Aliasl khiabani et al., 2020; Demirkesen & Mert, 2019).

CONCLUSION

In conclusion, the hardness and OBC of oleogel increased with higher oleogelation temperature from 70 to 90°C. The acid value decreased at the highest temperature (90°C), while the peroxide value decreased with the higher temperature. Based on the results, the optimal oleogelation temperature for peanut oil oleogel production was at 90°C. Storage test for 40 days showed that the hardness and OBC decreased over time by approximately 30% and 7%, respectively. Regarding oxidative stability, the acid, peroxide, and TBA values increased with the duration of storage, but after 40 days, the values remained below the recommended safe limits. Replacing shortening with peanut oil oleogel in cake formulation affected the viscosity, the final color, and the appearance or macrostructure of the resulting product. The use of peanut oil oleogel produced higher cake batter viscosity and cake with more uniform pore size. Nevertheless the texture profile, comprising hardness, cohesiveness, and springiness between cakes formulated with peanut oil oleogel and with shortening were comparable. Further studies should focus on the influence of cooling temperature on the physicochemical properties of peanut oil oleogel.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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