

Characterization Physicochemical Characteristics and Oxidative Stability of Red Palm Oil Oleogel Structured with Glyceryl Monostearate (GMS)

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ABSTRACT: Red palm oil (RPO) is a vegetable oil rich in carotenoids and antioxidant compounds; however, its application in food products remains limited due to its susceptibility to oxidation and its liquid form at room temperature. One approach to improve its stability and broaden its application is through oleogel formation using oleogelators. This study aimed to characterize the physicochemical properties and oxidative stability of red palm oil oleogels formulated with Glyceryl Monostearate (GMS). Oleogels were prepared using different concentrations of GMS, namely 6%, 8%, 10%, 12%, 14%, and 16% (w/w). The oleogels were characterized based on hardness, oil binding capacity (OBC), color, caroten content, peroxide value, and functional group analysis using Fourier Transform Infrared Spectroscopy (FTIR). The results showed that increasing GMS concentration influenced the physicochemical properties of red palm oil oleogels. Hardness increased from 0.12 N to 1.94 N, while oil binding capacity (OBC) ranged from 70.26% to 92.21%. The color parameters (L^* , a^* , and b^*) ranged from 29.43 to 35.24, 27.95 to 21.32, and 55.34 to 51.10, respectively. Total carotenoid content ranged from 265,32 to 626,05 ppm. FTIR analysis indicated that the formation of GMS-based oleogels was associated with intermolecular hydrogen bonding, which facilitated the development of a three-dimensional crystalline network within the oleogel system, thereby improving its ability to entrap the oil phase and maintain structural stability. The peroxide value ranged from 2.72 to 2.85 mEqO₂/kg the results indicated that there were no significant differences ($P > 0.05$), suggesting that the oleogelation process did not cause a significant increase in peroxide value. Accordingly, the oxidative stability of the system remained relatively unchanged during oleogel formation. These findings suggest that red palm oil oleogels may serve as a potential alternative lipid phase in margarine products.

KEYWORDS: red palm oil, oleogel, glyceryl monostearate (GMS), oleogelator, viscosity, physicochemical properties.

I. INTRODUCTION

Red palm oil (RPO) is a derivative of crude palm oil (CPO) that retains its natural carotenoids, particularly β -carotene, as well as vitamin E compounds including tocopherols and tocotrienols. These bioactive compounds contribute antioxidant activity and potential health benefits, highlighting the potential of RPO as a functional lipid source (Nawang et al., 2025). However, the application of RPO in food products remains limited due to its susceptibility to thermal degradation and oxidation, which may reduce product stability and quality. Consequently, RPO is commonly incorporated into products such as mayonnaise, salad dressings, spreads, and cream fillings (Wiguna et al., 2023). Hidayati et al. (2024) reported that carotenoids in RPO are highly prone to degradation during heat processing and oxygen exposure. In addition, Pakpahan (2023) identified limited oxidative stability as one of the major constraints restricting the utilization of RPO in lipid-based food products.

Oleogel is a semi-solid system formed by entrapping liquid oil within a three-dimensional network generated by oleogelators. This network immobilizes the oil phase and produces properties comparable to those of conventional solid fats (Yousuf et al., 2021). In recent years, oleogels have attracted considerable attention due to their formulation flexibility, ability to mimic solid fat characteristics, and potential to improve oil oxidative stability (Patel & Dewettinck, 2016). Ramezani et al. (2024) demonstrated that the crystalline network in oleogels can restrict lipid mobility and oxygen diffusion, thereby slowing oxidative deterioration. Similarly, previous studies have shown that oleogelation enhances oxidative stability compared to liquid oils through the formation of a more compact and stable crystal network (Giacomozzi et al., 2021).

Various oleogelators, including natural waxes and monoglycerides, have been employed in oleogel development. Although wax-based oleogels are capable of forming stable structures, their application is often associated with a waxy mouthfeel that may reduce sensory acceptance (Airoldi, 2022). In addition, wax-based oleogelators have been reported to affect the textural and sensory characteristics of certain food products (Leahu et al., 2023). Therefore, monoglycerides have emerged as a promising

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alternative oleogelator due to their ability to form stable crystalline networks with relatively neutral sensory properties (Palla et al., 2022). Monoglycerides are also known to effectively promote crystal formation, thereby improving the texture and stability of oleogels (Giacomozzi et al., 2021).

Several studies have demonstrated that monoglycerides can improve the physicochemical characteristics of oleogels formulated with various vegetable oils. Ogutcu et al. (2014) reported that monoglyceride incorporation in hazelnut oil-based oleogels increased hardness and oil binding capacity. Palla et al. (2020) further showed that increasing monoglyceride concentration resulted in a more stable crystalline network and improved the plasticity of sunflower oil-based oleogels. Similarly, Sim et al. (2021) observed enhanced thermal stability and textural properties in monoglyceride-based oleogels compared to non-structured liquid oils. Furthermore, Wu et al. (2025) reported that higher monoglyceride concentrations promoted the formation of a denser crystalline network, thus improving oleogel stability.

Characterization of the structure and physicochemical properties of oleogels is essential to understand the interactions between monoglycerides and red palm oil during gel network formation, as well as their influence on oleogel stability. Nevertheless, studies on the use of Glyceryl Monostearate (GMS) as an oleogelator in red palm oil systems remain limited, particularly regarding physicochemical characteristics and oxidative stability. Therefore, this study aimed to characterize the physicochemical properties and oxidative stability of red palm oil oleogels formulated with Glyceryl Monostearate (GMS). The findings of this study are expected to provide a scientific basis for the development of red palm oil oleogels as an alternative lipid phase in margarine products.

II. METODOLOGY

A. Materials and tools

The materials used for oleogel preparation and subsequent analyses included red palm oil (RPO), glyceryl monostearate (GMS), Span 80, Tween 80, water, whey protein isolate (WPI), flavoring agent, potassium sorbate, and salt. Analytical-grade chemicals employed in this study were 50% sodium hydroxide (NaOH), sulfuric acid (H_2SO_4), 0.1 N hydrochloric acid (HCl), nhexane, 0.1 N potassium hydroxide (KOH), potassium iodide (KI), starch solution, chloroform, acetic acid, sodium thiosulfate pentahydrate ($Na_2S_2O_3 \cdot 5H_2O$), and distilled water. The tools utilized in this study comprised Erlenmeyer flasks, beakers, volumetric pipettes, graduated pipettes, graduated cylinders, centrifuge tubes, a centrifuge, a vortex mixer, a magnetic stirrer, a UV–Vis spectrophotometer, a texture analyzer, an analytical balance, a thermometer, test tubes, sample bottles, spoons, and glass stirring rods.

B. Oleogel preparation

The first stage of the study was conducted based on the method described by Giacomozzi et al. (2021). The procedure was initiated by weighing the materials according to the proportion of each treatment. Monoglyceride (6%, 8%, 10%, 12%, and 14%, 16% w/w) was mixed with red palm oil and heated at 80°C for 35 minutes under continuous stirring at 400 rpm until the monoglyceride was completely dissolved, resulting in a homogeneous dispersion. Subsequently, the mixture was gradually cooled at room temperature to allow the monoglyceride and red palm oil molecules to form a stable and uniform semi-solid structure. The resulting oleogel was then stored in sealed containers at 4°C to maintain gel stability and minimize the oxidation of red palm oil.

C. Color analysis

Color analysis was conducted following the method of Chouikhi et al. (2023) using a color reader. Color attributes were determined according to the CIELAB color space and expressed as L^* (lightness), a^* (redness–greenness), and b^* (yellowness–blueness). Prior to measurement, the samples were transferred into a sample container, after which color readings were recorded directly from the instrument. The resulting L^* , a^* , and b^* values were used to characterize the color properties of the samples.

D. Hardness analysis

Hardness was measured using a Texture Analyzer TA.XT Plus according to the method of Purnomo (2014). The probe was positioned above the sample surface, and measurements were carried out at a pre-test speed of 2.0 mm/s, a test speed of 2.0 mm/s, and a post-test speed of 5.0 mm/s. The test was performed using a distance of 5.0 mm, a holding time of 5.0 s, and a penetration depth of 10 mm. The maximum force recorded during sample penetration was taken as the hardness value and expressed in Newtons (N).

E. Oil binding capacity (OBC)

The oil binding capacity (OBC) of the oleogel samples was evaluated according to the method described by Meng et al. (2018) with minor modifications. Approximately 1 g of oleogel was placed in a pre-weighed 2 mL centrifuge tube and centrifuged at 10,000

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rpm for 15 min at 25°C. Following centrifugation, the expelled oil was decanted, and the tube was reweighed. The OBC was calculated from the mass difference before and after centrifugation according to the following equation:

$$\text{Oil loss (\%)} = \frac{(M_1 - M) - (M_2 - M)}{(M_1 - M)} \times 100\%$$

where:

M = weight of the empty centrifuge tube (g)

M₁ = weight of the centrifuge tube containing the sample before centrifugation (g)

M₂ = weight of the centrifuge tube containing the sample after centrifugation (g)

F. Fourier Transform Infrared (FTIR)

FTIR analysis was conducted using an FTIR spectrometer equipped with an Attenuated Total Reflectance (ATR) accessory according to the method of Dimakopoulou-Papazoglou et al. (2023). The oleogel samples were placed on the ATR crystal surface and scanned within the wavenumber range of 4000–500 cm⁻¹. The resulting infrared spectra were analyzed to identify the characteristic functional groups present in the red palm oil oleogel.

G. Caroten analysis

Total carotenoid content was determined according to the PORIM (1995) method using a UV–Vis spectrophotometer. Briefly, 0.1 g of sample was transferred into a 25 mL volumetric flask and diluted to volume with n-hexane. The solution was then homogenized, and its absorbance was measured at 446 nm. The total carotenoid content was subsequently calculated from the absorbance value using the following equation:

$$\text{Total carotenoid content (ppm)} = \frac{A \times 383 \times 25}{W \times 100}$$

where:

A = absorbance measured at 446 nm

W = sample weight (g)

H. Peroxide value analysis

Peroxide value (PV) was determined according to the European Pharmacopoeia (2005) using the iodometric titration method. Briefly, 5 g of sample was weighed into an Erlenmeyer flask and mixed with 30 mL of a glacial acetic acid–chloroform solution (3:2, v/v). Subsequently, 0.5 mL of saturated potassium iodide solution was added, and the mixture was shaken for 1 min in the dark. Afterward, 30 mL of distilled water was added, and the liberated iodine was titrated with 0.01 N sodium thiosulfate pentahydrate (Na₂S₂O₃·5H₂O) until a pale yellow color was obtained. Then, 5 mL of 1% starch solution was added as an indicator, and the titration was continued until the blue color disappeared. A blank determination was performed using distilled water following the same procedure. The peroxide value was calculated using the following equation:

$$\text{Peroxide value (mEqO}_2\text{/kg)} = \frac{N \times 1000 \times (V_t - V_b)}{W}$$

where:

N = normality of Na₂S₂O₃·5H₂O

V_t = volume of sodium thiosulfate solution used for sample titration (mL)

V_b = volume of sodium thiosulfate solution used for blank titration (mL) W = sample weight (g)

III. RESULT AND DISCUSSION

A. Color Analysis (L*, a*, b*)

Table 1. L*, a*, b* Color Values

GMS Concentration (%)	L*	a*	b*
OM1 (6%)	29,43 ± 0,41 ^f	27,95 ± 0,10 ^a	55,34 ± 0,62 ^a
OM2 (8%)	31,58 ± 0,39 ^e	25,93 ± 0,20 ^b	54,22 ± 0,33 ^a
OM3 (10%)	32,50 ± 0,50 ^d	24,79 ± 0,64 ^c	53,52 ± 0,51 ^b
OM4 (12%)	33,46 ± 0,23 ^c	23,71 ± 0,47 ^d	53,29 ± 0,64 ^b

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OM5 (14%)	34,19 ± 0,32 ^b	22,53 ± 0,38 ^e	52,44 ± 0,48 ^b
OM6 (16%)	35,24 ± 0,29 ^a	21,32 ± 0,25 ^f	51,10 ± 0,74 ^c

Note: Values are expressed as mean ± standard deviation. Different superscript letters within the same column indicate significant differences among treatments ($P < 0.05$).

I. L^* Values

Analysis of variance showed that GMS concentration had a significant effect ($P < 0.05$) on the L^* value of red palm oil-based oleogels, as presented in Table 1. The L^* value indicates the lightness level of a color, ranging from 0 to 100, where 0 represents black and 100 represents white (Komalasari et al., 2025). Based on Table 1, the average L^* values of red palm oil-based oleogels ranged from 29.43 to 35.24. The highest L^* value was observed in treatment OM6 with an average value of 35.24. Whereas the lowest L^* value was observed in treatment OM1 with an average value of 29.43.

The increase in L^* values may be attributed to the greater formation of GMS crystals within the oleogel system, which enhanced light scattering and resulted in a brighter appearance of the oleogel. Furthermore, increasing the GMS concentration reduced the proportion of red palm oil in the formulation, thereby decreasing the intensity of the orange-red color imparted by carotenoid pigments. These results are consistent with the findings of Zhang et al. (2023), who reported that increasing monoglyceride concentration promotes crystal formation within oleogel systems. The development of a denser crystalline network enhances light scattering, contributing to an increase in brightness. Similarly, Dimakopoulou-Papazoglou et al. (2023) demonstrated that monoglyceride concentration significantly influences the physical and visual properties of oleogels. Therefore, the higher L^* values observed at elevated GMS concentrations may be associated with both increased crystal formation and the reduced contribution of red palm oil pigments to the overall color of the oleogel.

II. a^* Values

Analysis of variance showed that GMS concentration had a significant effect ($P < 0.05$) on the a^* value of red palm oil-based oleogels, as presented in Table 1. The a^* value represents the color position along the red–green axis, where positive (+) values indicate a tendency toward red and negative (–) values indicate a tendency toward green (Komalasari et al., 2025). Based on Table 1, the average a^* values of red palm oil-based oleogels ranged from 27.95 to 21.32. The highest a^* value was observed in treatment OM1 with an average value of 27.95, whereas the lowest a^* value was observed in treatment OM6 with an average value of 21.32.

The a^* value of red palm oil oleogel decreased significantly with increasing GMS concentration, indicating a reduction in red color intensity. This phenomenon can be attributed to the decreasing proportion of red palm oil in the formulation as the GMS concentration increased. Because red palm oil is the primary source of carotenoid pigments, which impart the characteristic red-orange color, a reduction in its proportion resulted in a lower carotenoid content within the oleogel system. Consequently, the red color intensity diminished, leading to lower a^* values.

These findings are consistent with those reported by Rossi et al. (2017), who identified carotenoids as the principal pigments responsible for the red-orange coloration of red palm oil. As the concentration of GMS increased, the relative amount of red palm oil decreased, thereby reducing the contribution of carotenoid pigments to the overall color of the oleogel. This reduction in pigment concentration likely explains the progressive decline in a^* values observed at higher GMS concentrations.

III. b^* Values

Analysis of variance showed that GMS concentration had a significant effect ($P < 0.05$) on the b^* value of red palm oil-based oleogels, as presented in Table 1. The b^* value represents the color position along the yellow–blue axis, where positive (+) values indicate a tendency toward yellow and negative (–) values indicate a tendency toward blue (Komalasari et al., 2025). Based on Table 1, the b^* values of the oleogels ranged from 55.34 to 51.10. The highest b^* value was observed in treatment OM1 (55.34), whereas the lowest value was recorded in treatment OM6 (51.10).

The b^* value of red palm oil oleogel decreased significantly with increasing GMS concentration, indicating a reduction in yellow color intensity. This behavior can be attributed to the decreasing proportion of red palm oil in the formulation as the GMS concentration increased. Because carotenoids are the major pigments responsible for the characteristic yellow-orange to red-orange coloration of red palm oil, a lower proportion of red palm oil resulted in a reduced concentration of these pigments within the oleogel matrix. Consequently, the contribution of carotenoids to the overall color of the oleogel diminished, leading to lower b^* values. These results are in agreement with Rossi et al. (2017), who reported that carotenoids are the principal pigments responsible for the characteristic color of red palm oil. Therefore, the progressive decline in b^* values at higher GMS concentrations is likely associated with the reduced carotenoid content resulting from the lower proportion of red palm oil in the oleogel formulation.

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B. Hardness

Table 2. Hardness Values

GMS Concentration (%)	Hardness (N)
OM1 (6%)	0,12 ± 0,01 ^f
OM2 (8%)	0,45 ± 0,05 ^e
OM3 (10%)	0,68 ± 0,04 ^d
OM4 (12%)	0,85 ± 0,05 ^c
OM5 (14%)	1,83 ± 0,09 ^b
OM6 (16%)	1,94 ± 0,04 ^a

Note: Values are expressed as mean ± standard deviation. Different superscript letters within the same column indicate significant differences among treatments ($P < 0.05$).

Hardness represents the maximum force required to compress a food product until deformation occurs (Huang et al., 2023). Analysis of variance showed that GMS concentration in red palm oil-based oleogels significantly affected ($p < 0.05$) the hardness values of the oleogels. Higher hardness values generally indicate the formation of a stronger and more stable oleogel structure (Malvano et al., 2024). As presented in Table 2, the mean hardness values of the oleogels ranged from 0.12 N to 1.94 N. The highest mean hardness value was observed in treatment OM6, with a value of 1.94 N, while the lowest value was recorded in treatment OM1, at 0.12 N. The increase in hardness with increasing GMS concentration indicates that a higher amount of oleogelator contributes to the formation of a denser and stronger crystalline network, thereby enhancing the resistance of the oleogel to deformation (Zhang et al., 2023). Increasing GMS concentration in the oil phase promoted the formation of a denser three-dimensional network and improved the structural integrity of the oleogel, resulting in enhanced mechanical properties of the system (Ramezani et al., 2024). These findings are consistent with those reported by Zhang et al. (2023) in sunflower oil-based oleogels, where increasing monoglyceride concentration enhanced gel strength and improved the physical properties of oleogels due to the formation of a more compact and continuous crystalline network.

C. Oil Binding Capacity (OBC)

Table 3. Oil Binding Capacity (OBC) Values

GMS Concentration (%)	Oil Binding Capacity (%b/b)
OM1 (6%)	70,26 ± 1,47 ^e
OM2 (8%)	80,12 ± 1,18 ^d
OM3 (10%)	85,29 ± 0,59 ^c
OM4 (12%)	86,08 ± 0,54 ^c
OM5 (14%)	90,45 ± 0,82 ^b
OM6 (16%)	92,21 ± 0,49 ^a

Note: Values are expressed as mean ± standard deviation. Different superscript letters within the same column indicate significant differences among treatments ($P < 0.05$).

Oil binding capacity (OBC) reflects the ability of oleogels to retain or immobilize oil within their structural network (Ramezani et al., 2024). Based on analysis of variance, GMS concentration had a significant effect ($p < 0.05$) on the OBC of the oleogels. The mean OBC values are presented in Table 3. Oleogel containing 6% GMS exhibited the lowest OBC value (70.26%), whereas oleogel containing 16% GMS showed the highest OBC value (92.21%). This increase may be attributed to the greater amount of oleogelator involved in the formation of crystalline networks, which reduced *oil loss* and enhanced the mechanical strength of the system (Zhang et al., 2023). Increasing oleogelator concentration in the oil phase contributed to the formation of a denser and more stable oleogel network. Such a structure enhanced the oil-binding ability of the oleogel, thereby reducing oil mobility and suppressing *oil loss* (Ramezani et al., 2024).

The present findings are consistent with those reported by Zhang et al. (2023), who observed in sunflower oil-based oleogels that increasing monoglyceride concentration significantly improved OBC, from 79.88% at 4% concentration to more than 98% at 8–10%, due to the formation of a more compact and continuous three-dimensional crystalline network. Similar results were

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reported by Ghan et al. (2022) in *palm olein* organogels formulated with GMS and lecithin, where increasing GMS proportion resulted in higher OBC values as a consequence of enhanced gel stability and reduced oil mobility. Furthermore, Malvano et al. (2024) reported low oil release in GMS-based oleogels prepared using olive oil and peanut oil, indicating high oilbinding capacity associated with the formation of a strong crystalline network. A similar mechanism is likely to occur in red palm oil oleogels in the present study, where increasing GMS concentration resulted in progressively higher OBC values due to the development of a denser and more stable gel matrix.

D. Fourier Transform Infrared (FTIR) Spectroscopy

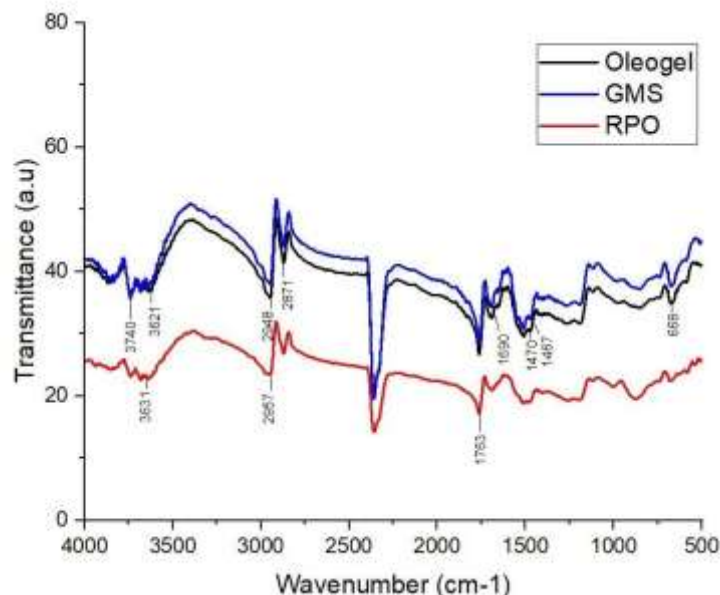


Figure 1. Fourier transform infrared (FTIR) spectra profile

FTIR analysis was performed to identify the functional groups and to elucidate the intermolecular interactions involved in the formation of red palm oil-based oleogels structured with GMS. The FTIR spectra were obtained for GMS, red palm oil (RPO), and the oleogel sample exhibiting the highest hardness value (OM6).

The FTIR spectra exhibited absorption peaks at 3740–3621 cm^{-1} , corresponding to the O–H stretching vibration of the hydroxyl groups in GMS, whereas the peaks at 2957–2948 cm^{-1} and 2871 cm^{-1} were attributed to the C–H stretching vibrations of fatty acid hydrocarbon chains. The absorption peak at 1763 cm^{-1} was assigned to the stretching vibration of ester carbonyl (C=O), a characteristic functional group of red palm oil triglycerides and GMS monoglycerides, while the peak at 1467 cm^{-1} corresponded to the CH₂ bending vibration commonly observed in lipid systems.

The FTIR spectrum of OM6 exhibited functional groups similar to those observed in red palm oil and GMS. The presence of hydroxyl (O–H) and ester carbonyl (C=O) groups suggested the occurrence of intermolecular interactions through hydrogen bond formation between the hydroxyl groups of GMS and the ester carbonyl groups within the lipid system. These interactions were presumed to contribute to the development of a three-dimensional network responsible for the gelation process and structural stabilization of the oleogel. These findings are consistent with those reported by Ghan et al. (2022), Ramezani et al. (2024), and Malvano et al. (2024), who demonstrated that the formation of monoglyceride-based oleogels involves intermolecular interactions mediated by hydrogen bonding.

E. Caroten Content

Table 4. Caroten Content Values

GMS Concentration (%)	Caroten Content (ppm)
OM1 (6%)	626,05 ± 5,64 ^a
OM2 (8%)	438,78 ± 4,68 ^b
OM3 (10%)	402,42 ± 6,02 ^c
OM4 (12%)	347,41 ± 7,28 ^d

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OM5 (14%)	318,38 ± 9,44 ^e
OM6 (16%)	265,32 ± 4,49 ^f

Note: Values are expressed as mean ± standard deviation. Different superscript letters within the same column indicate significant differences among treatments ($P < 0.05$).

Analysis of variance showed that GMS concentration significantly affected ($P < 0.05$) the total carotenoid content of red palm oil-based oleogels, as presented in Table 4. The total carotenoid content ranged from 265 to 626 ppm. The highest value was obtained for OM1 (626.05 ppm), whereas the lowest value was observed for OM6 (265.32 ppm). The decrease in total carotenoid content with increasing GMS concentration was associated with the lower proportion of red palm oil in the formulation. Red palm oil is recognized as a rich source of carotenoids, particularly β -carotene and α -carotene, which contribute to its characteristic color and nutritional properties (Gao et al., 2023). Therefore, reducing the proportion of red palm oil in the system resulted in a lower carotenoid content in the resulting oleogels. A similar trend was reported by Pakpahan et al. (2023), who found that oleogelator formulation and concentration significantly influenced the total carotenoid content of red palm oilbased oleogels. These results suggest that the carotenoid content of the oleogels was primarily governed by the proportion of red palm oil as the major source of carotenoids in the system.

F. Peroxide Value Analysis

Table 5. Peroxide Values

GMS Concentration (%)	Peroxide Values (mEqO ₂ /kg)
OM1 (6%)	2,74 ± 0,06 ^a
OM2 (8%)	2,76 ± 0,03 ^a
OM3 (10%)	2,82 ± 0,11 ^a
OM4 (12%)	2,81 ± 0,13 ^a
OM5 (14%)	2,72 ± 0,03 ^a
OM6 (16%)	2,85 ± 0,07 ^a

Note: Values are expressed as mean ± standard deviation. Different superscript letters within the same column indicate significant differences among treatments ($P < 0.05$).

Peroxide value is an important parameter for assessing primary oxidation in fats and oils, reflecting the quality and oxidative stability of the final product (Asbbane et al., 2024). Based on the analysis of variance presented in Table 5, the peroxide value of red palm oil oleogels showed no significant effect ($P > 0.05$), ranging from 2,72 to 2,85 mEqO₂/kg. The relatively uniform peroxide values indicate that increasing GMS concentration up to 16% did not significantly affect the primary oxidation level of the red palm oil oleogels.

The peroxide value of red palm oil prior to oleogelation was 2.40 mEqO₂/kg, which was slightly lower than that of the oleogel samples. The slight increase in peroxide value after oleogel formation may be attributed to the heating process during oleogel preparation, which can promote lipid oxidation. Nevertheless, the relatively low peroxide values across all treatments indicate that the oxidative quality of the oleogels remained well preserved. According to Dimakopoulou-Papazoglou et al. (2024), monoglyceride-based oleogels are capable of maintaining the oxidative stability of oils, as evidenced by low peroxide values. This suggests that the crystalline network formed within the oleogel system may help protect the oil from oxidation. Therefore, although the oleogelation process led to a slight increase in peroxide value compared to the initial red palm oil, increasing GMS concentration did not result in any significant changes in the oxidative status of the resulting oleogels.

IV. CONCLUSION

The addition of Glyceryl Monostearate (GMS) significantly affected the physicochemical properties of red palm oil oleogels. Higher GMS concentrations resulted in increased hardness and oil binding capacity (OBC), indicating the formation of a denser and more stable oleogel network. The L*, a*, and b* values revealed that the characteristic color of red palm oil was retained in all oleogel samples. FTIR analysis suggested that intermolecular hydrogen bonding contributed to the formation of a three-dimensional crystalline network, which played an important role in maintaining the structural stability of the GMS-based oleogels. Carotenoid content ranged from 265,32 to 626,05 ppm, whereas peroxide values varied between 2,72 and 2,85 mEqO₂/kg. Overall, GMS

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effectively structured red palm oil into oleogels with desirable physicochemical properties and good stability, highlighting their potential use as an alternative lipid phase in margarine formulations.

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REFERENCES

- 1) B. Wiguna, J. Kahfi, G. K. Aji, D. Rachman, A. S. Nasori, M. Muhamaludin, E. Maryana, P. Atmaji, D. Taniwiryono, W. Purwanto, and I. B. Susetyo, "The influence of virgin red palm oil on the physical and textural properties of various vegetable full-fat mayonnaise," *Sains Malaysiana*, vol. 52, no. 10, pp. 2843–2854, 2023, doi: 10.17576/jsm-2023-5210-09.
- 2) S. Hidayati, F. Nurainy, E. Suroso, Subeki, D. Sartika, and S. Hadi, "Effect of heating time on changes in physicochemical properties and fatty acid composition of red palm oil," *Afr. J. Food Agric. Nutr. Dev.*, vol. 24, no. 2, pp. 25628–25644, 2024, doi: 10.18697/ajfand.127.23005.
- 3) N. Pakpahan, S. Maryati, and D. Susanti, "Characteristics of oleogel prepared from red palm oil using hybrid oleogelator," *E3S Web Conf.*, vol. 373, 2023.
- 4) M. Yousuf, F. Y. B. Ahmed, S. M. Z. Abidin, and N. A. B. M. Ali, "Oleogel-based systems for the delivery of bioactive compounds in foods," *Gels*, vol. 7, no. 3, p. 86, 2021, doi: 10.3390/gels7030086.
- 5) A. R. Patel and K. Dewettinck, "Edible oleogels and their structuring potential in food: A review," *Food Funct.*, vol. 7, no. 1, pp. 20–29, 2016, doi: 10.1039/C5FO01006C.
- 6) M. Ramezani, L. Salvia-Trujillo, and O. Martín-Belloso, "Modulating edible-oleogels physical and functional characteristics by controlling their microstructure," *Food & Function*, vol. 15, no. 2, pp. 663–675, 2024, doi: 10.1039/D3FO03491G.
- 7) F. Giacomozzi, A. G. Marangoni, and A. D. Martini, "Structure–function relationships in oleogels: Impact of crystal network on oil binding and stability," *Food Hydrocolloids*, vol. 119, p. 106828, 2021, doi: 10.1016/j.foodhyd.2021.106828.
- 8) R. Airoidi, T. L. T. da Silva, J. N. R. Ract, A. Foguel, H. L. Colleran, S. A. Ibrahim, and R. C. da Silva, "Potential use of carnauba wax oleogel to replace saturated fat in ice cream," *J. Am. Oil Chem. Soc.*, vol. 99, no. 12, pp. 1287–1299, 2022, doi: 10.1002/aocs.12652.
- 9) A. Leahu, C. M. Popa, M. Nistor, and I. A. Râpeanu, "Wax-based oleogels and their influence on the textural and sensory properties of food systems: A review," *Foods*, vol. 12, no. 5, p. 1089, 2023, doi: 10.3390/foods12051089.
- 10) C. A. Palla, M. Domínguez, and M. E. Carrín, "Recent advances on food based applications of monoglyceride oleogels," *J. Am. Oil Chem. Soc.*, vol. 99, no. 7, pp. 767–786, 2022, doi: 10.1002/aocs.12617.
- 11) M. Ögütcü and E. Yılmaz, "Oleogels of virgin olive oil with monoglyceride and carnauba wax as spreadable products," *J. Am. Oil Chem. Soc.*, vol. 91, no. 6, pp. 1007–1017, 2014, doi: 10.1007/s11746-014-2434-1.
- 12) C. A. Palla, M. F. Wasinger, and M. E. Carrín, "Monoglycerides oleogels as fat replacers in filling creams for sandwich cookies," *J. Am. Oil Chem. Soc.*, vol. 97, no. 10, pp. 1121–1133, 2020, doi: 10.1002/aocs.12412.
- 13) S. Y. J. Sim, X. W. Kah, and J. H. Christiani, "Healthier pineapple tart pastry using oleogel-based solid fat replacement," *Malays. J. Nutr.*, vol. 27, no. 2, pp. 231–244, 2021.
- 14) Z. Wu, W. Zeng, X. Xu, W. Chen, and G. Liu, "Enhancement of resistant starch content in ethyl cellulose-based oleogel cakes with the incorporation of glycerol monostearate," *Food Hydrocoll.*, vol. 152, p. 109291, 2025, doi: 10.1016/j.foodhyd.2024.109291.
- 15) A. Chouikhi, N. Ktari, S. Ben Slima, I. Trabelsi, F. Bendali, and R. Ben Salah, "Effects of a novel lin seed polysaccharide on beef sausage properties," *Polymers*, vol. 15, no. 4, 2023, doi: 10.3390/polym15041014.
- 16) E. H. Purnomo, "Texture of snack food," *Food Review Indonesia*, vol. 9, no. 7, 2014.
- 17) Z. Meng, K. Qi, Y. Guo, Y. Wang, and Y. Liu, "Effects of thickening agents on the formation and properties of edible oleogels based on hydroxypropyl methyl cellulose," *Food Chem.*, vol. 246, pp. 137–149, 2018.
- 18) D. Dimakopoulou-Papazoglou, F. Giannakaki, and E. Katsanidis, "Structural and physical characteristics of mixed component oleogels: Natural wax and monoglyceride interactions in different edible oils," *Gels*, vol. 9, no. 8, p. 627, 2023, doi: 10.3390/gels9080627.

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- 19) PORIM, *PORIM Test Methods*. Kuala Lumpur, Malaysia: Palm Oil Research Institute of Malaysia, 1995.
- 20) *European Pharmacopoeia*, 5th ed. Strasbourg, France: Council of Europe, 2005.
- 21) H. Komalasari, C. A. Afgani, and A. Melandani, "Karakterisasi dan pemetaan profil fisikokimia dangke susu kuda liar khas Nusa Tenggara Barat," *J. Teknol. Mutu Pangan*, vol. 3, no. 2, pp. 80–87, 2025, doi: 10.30812/jtmp.v3i2.4776.
- 22) M. Rossi, M. Gianazza, C. Alamprese, and F. Stanga, "The effect of bleaching and physical refining on color and minor components of palm oil," *Eur. J. Lipid Sci. Technol.*, vol. 119, no. 6, p. 1600400, 2017.
- 23) L. Huang, Y. Cai, D. Fang, J. Su, M. Zhao, Q. Zhao, and P. Van der Meeren, "Formation and characterization of oleogels derived from emulsions: Evaluation of polysaccharide ratio and emulsification method," *Food Hydrocoll.*, vol. 142, p. 108844, 2023, doi: 10.1016/j.foodhyd.2023.108844.
- 24) F. Malvano, D. Albanese, L. Cinquanta, S. Liparoti, and F. Marra, "A comparative study between beeswax and glycerol monostearate for food-grade oleogels," *Gels*, vol. 10, no. 4, p. 214, 2024, doi: 10.3390/gels10040214.
- 25) S. Y. Ghan, L. F. Siow, C. P. Tan, K. W. Cheong, and Y. Y. Thoo, "Palm olein organogelation using mixtures of soy lecithin and glyceryl monostearate," *Gels*, vol. 8, no. 1, p. 30, 2022, doi: 10.3390/gels8010030.
- 26) Z. Gao, Y. Zhu, J. Jin, Q. Jin, and X. Wang, "Chemical–physical properties of red palm oils and their application in the manufacture of aerated emulsions with improved whipping capabilities," *Foods*, vol. 12, no. 21, p. 3933, 2023, doi: 10.3390/foods12213933.
- 27) A. Asbbane, Z. Bousaid, D. Guillaume, S. El Harkaoui, B. Matthäus, Z. Charrouf, K. W. Goh, N. Srasom, A. Bouayahya, and S. Gharby, "Effects of physical refining process on quality and stability of argan oil (*Argania spinosa* (L.) Skeels)," *Sci. Rep.*, vol. 14, no. 1, p. 23045, 2024, doi: 10.1038/s41598-024-74466-6.



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