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Original Research Article

Formulation of Chia Seed Oil (Salvia hispanica) Nanoemulgel as An Antioxidant

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Abstract

Chia seed oil (Salvia hispanica) contains bioactive compounds, including tocopherols and phenolics, which exhibit antioxidant properties against free radicals. This study aimed to evaluate the antioxidant activity of chia seed oil, determine the optimal nanoemulsion formulation based on physical characteristics and antioxidant activity, and develop a nanoemulgel preparation. Antioxidant activity was assessed using the DPPH method. Nanoemulsion optimization was performed by varying concentrations of the surfactant Cremophor RH 40 and cosurfactant PEG 400. The best formulation (Formula 1) consisted of Cremophor RH 40 (80%), PEG 400 (10%), and chia seed oil (5%). The selected nanoemulsion was incorporated into a nanoemulgel containing 30% nanoemulsion and 70% gel base composed of Carbopol (0.5%), DMDM hydantoin (0.5%), and propylene glycol (5%). The nanoemulgel was evaluated for organoleptic properties, pH, viscosity, homogeneity, spreadability, adhesiveness, emulsion type, stability, and antioxidant activity. Results demonstrated that the formulation possessed good and stable physical characteristics, with very strong antioxidant activity (IC_{50} = 22.10 ppm). These findings indicate its potential for development as a natural-based pharmaceutical and cosmetic product.

Keywords: antioxidant, chia seed oil, DPPH, nanoemulgel, topical formulation

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1 Introduction

Free radicals are atoms or molecules that are unstable and highly reactive due to the presence of one or more unpaired electrons in their outer orbitals. To achieve stability, free radicals interact with surrounding molecules to obtain the necessary electron pairs. The formation of free radicals in the body can be triggered by various factors, including exposure to pollutants, radiation, chemicals, as well as the consumption of fast foods and foods fried at high temperatures. An excessive accumulation of free radicals that is not balanced by the body's antioxidant defense system can lead to oxidative stress, which has the potential to damage important biomolecules in the body [1], [2], [3].

Antioxidants are compounds capable of inhibiting or neutralizing oxidation reactions by scavenging free radicals, thereby preventing oxidative damage to biological molecules. Antioxidants can be derived from both synthetic and natural sources. Some commonly used synthetic antioxidants include butylated hydroxytoluene (BHT), ascorbic acid, kojic acid, mercury, and hydroquinone. However, the use of certain synthetic antioxidants at high concentrations has been reported to cause adverse effects, such as carcinogenic properties and the potential to induce skin irritation or damage. Therefore, the utilization of natural antioxidants derived from biological resources has become a safer alternative. Natural antioxidants are widely found in plants, particularly in the form of polyphenolic compounds (such as flavonoids, phenolic acids, anthocyanins, and lignin), carotenoids, and vitamins such as vitamin C and vitamin E [1], [2], [3], [4].

One plant with potential as a natural antioxidant source is chia (*Salvia hispanica L.*). This annual herbaceous plant originates from Northern Guatemala and Southern Mexico and is currently widely cultivated in various countries with tropical and subtropical climates. In recent years, chia seeds have become increasingly available in Southeast Asian countries, including Indonesia, through international trade and the growing functional food market. At present, chia seeds can be easily obtained in various supermarkets and health food stores in Indonesia, reflecting their increasing commercial availability [5]. Most chia seeds in Indonesia are imported, with the country bringing in approximately 2.8 million kg in 2023, indicating the growing demand of this commodity [6]. Chia seeds are widely utilized in various products, including food, animal feed, and applications in the medical, cosmetic, and pharmaceutical industries due to their non-toxic and gluten-free characteristics, making them relatively safe for consumption [7]. However, the development of chia-based cosmetic products remains limited, particularly in Indonesia, despite the presence of bioactive compounds with potential benefits for skin.

Chia seeds are known to contain various bioactive compounds with high antioxidant activity, including phenolic acids (gallic acid, caffeic acid, chlorogenic acid, cinnamic acid, ferulic acid, and p-coumaric acid), flavonoids (quercetin, kaempferol, epicatechin, rutin, and apigenin), as well as other antioxidant compounds such as tocopherols and sterols [8]. Tocopherols are lipid-soluble antioxidants that play an important role in protecting cell membranes from damage caused by free radicals and provide benefits for skin health, such as maintaining moisture, reducing wrinkles, and assisting in wound healing. Shen et al. (2018) reported that chia seed oil contains approximately 76.96 mg/kg of tocopherols, mainly composed of γ-tocopherol (91%) and α-tocopherol (6.6%). Chia seed oil has also been reported to exhibit relatively strong antioxidant activity with an IC_{50} value of 33.94 mg/L using the DPPH method [9].

Despite its significant potential as an active ingredient, natural oils generally possess several limitations, such as susceptibility to oxidative degradation, low stability, and limited penetration in topical applications. Therefore, an appropriate delivery system is required to improve their stability and effectiveness. One approach that can be applied is the nanoemulsion system. Nanoemulsions are dispersions of oil in water or vice versa stabilized by surfactants, with droplet sizes ranging from 20–200 nm[10], [11], [12]. The very small particle size increases the surface area, thereby enhancing the penetration of active compounds through the stratum corneum and improving their bioavailability [13].

Cremophor RH 40 was selected as the surfactant in this study due to its high hydrophilic–lipophilic balance (HLB) value of approximately 14–16, classifying it as a hydrophilic nonionic surfactant capable of

forming oil-in-water (O/W) emulsions. Surfactants with high HLB values, such as Cremophor RH 40, are known to enhance the efficiency of spontaneous nanoemulsion formation by reducing interfacial tension between the oil and water phases [14]. In addition, Cremophor RH 40 has been reported to inhibit the Ostwald ripening phenomenon in nanoemulsion systems, thereby improving formulation stability over extended storage periods, nontoxic, and shows little tendency to foam [15], [16]. PEG 400 was used as a co-surfactant due to its hydrophilic nonionic nature and HLB value of 13.1, which helps reduce interfacial tension and increase the flexibility of the interfacial film in O/W systems [16]. Its affinity for both oil and water phases supports surfactants in stabilizing the nanoemulsion structure and promotes spontaneous nanoemulsion formation during the emulsification process by illing gaps within the nanoemulsion structure and promoting hydrogen bonding interactions during the emulsification process [15]. Moreover, PEG 400 is widely used in pharmaceutical formulations due to its chemical stability, low toxicity, and non-irritating properties, making it a suitable co-surfactant for nanoemulsion preparation [17], [18].

A further development of the nanoemulsion system is nanoemulgel, which is a nanoemulsion dispersed within a gel matrix. This combination produces a formulation with good stability, ease of application, and improved permeation of active compounds through the skin. Compared with conventional cream formulations, nanoemulgel exhibits better spreadability and faster absorption due to its very small particle size [19], [20], [21].

Based on the bioactive potential of chia seed oil and the advantages of the nanoemulgel delivery system, this study aims to develop a nanoemulgel formulation of chia seed oil using Cremophor RH 40 as surfactant and PEG 400 as co-srufactant, to evaluate its physical characteristics, stability, and antioxidant activity using the DPPH method.

2 Method

2.1 Formulation of Chia Seed Oil Nanoemulgel

Nanoemulsions were prepared by mixing chia seed oil as the oil phase with a surfactant (Cremophor RH40) and a co-surfactant (PEG 400) using the following formulations: F1 (5% : 80% : 10%), F2 (5% : 70% : 20%), and F3 (5% : 60% : 30%). The mixture was stirred using a magnetic stirrer at a speed of 500 rpm at 40 °C for 15 minutes. Subsequently, distilled water was added gradually at the same temperature until a homogeneous mixture was obtained. The resulting mixture was then sonicated using a bath sonicator for 90 minutes [16], [18], [22].

The gel base was prepared by dispersing 0.5 g of Carbopol 940 in 94 ml of hot water and allowing it to swell, followed by stirring until a homogeneous gel mass was formed. Subsequently, 5 g of propylene glycol, 0.5 g of DMDM hydantoin, and three drops of triethanolamine (TEA) were gradually added, and the mixture was stirred until a homogeneous gel base was obtained [23]. Nanoemulgel was subsequently prepared by incorporating 30% of best nanoemulsion formula into 70% gel base and mixing until a homogeneous formulation was obtained.

2.2 Physical Characterization of Chia Seed Oil Nanoemulgel

The three nanoemulsion formulations of chia seed oil (F1, F2, and F3) were subjected to physical evaluation, including organoleptic testing, pH measurement using a pH meter, viscosity measurement using a Brookfield viscometer, percent transmittance (% transmittance) measurement at 650 nm using a UV–Vis spectrophotometer, and droplet size as well as polydispersity index (PDI) analysis using a particle size analyzer (PSA) [24].

Subsequently, the nanoemulgel was evaluated for the following parameters:

a. Organoleptic test. The organoleptic properties of the nanoemulgel were evaluated through visual observation, including color, odor, and clarity [22].
b. Emulsion type test. One to two drops of nanoemulgel were placed on a glass slide, followed by the addition of 1–2 drops of methylene blue. The mixture was gently stirred using a glass rod. If the

methylene blue dispersed evenly, the formulation was classified as an oil-in-water (O/W) emulsion. Conversely, if blue spots were observed, the formulation was classified as a water-in-oil (W/O) emulsion [25].

c. Spreadability test. A total of 0.5 g nanoemulgel was placed on a transparent circular glass plate, and the initial diameter of the spread was measured. The sample was then covered with another transparent circular glass plate, followed by the addition of a 100 g load. After a certain time interval, the diameter of the spread was measured again. According to the Indonesian National Standard (SNI 06-2588-1992), a good spreadability value ranges from 5 to 7 cm [22].
d. Adhesion test. A total of 0.25 g nanoemulgel was weighed and placed in the center of a cover glass, then covered with another cover glass. A load of 100 g was applied and allowed to stand for 5 minutes. Afterward, the load was removed, and the two adhered glass plates were separated while recording the time required for the plates to detach from each other. The acceptable adhesion time for topical formulations is not less than 4 seconds [19].
e. Viscocity test. A total of 30 mL nanoemulgel was used to measure viscosity using a Brookfield viscometer with spindle number 4. The viscosity value appeared on the display screen, and once the reading became stable, the value was recorded according to the scale shown on the viscometer [22].
f. pH test. The pH meter was first calibrated using buffer solutions of pH 4.0 and 7.0. The electrode was then immersed in the nanoemulgel, and the pH value was measured and recorded from the instrument display [22].
g. Homogenity test. The homogeneity test was performed using a glass slide or another suitable transparent material. A total of 0,25 g nanoemulgel were spread onto a glass slide and then covered with a cover glass. The formulation was considered homogeneous if it showed a uniform appearance and no coarse particles were observed [22].
h. Stability test. The stability test was conducted using the cycling test method. The nanoemulgel was stored at 4 °C for 24 hours and then transferred to 40 °C for another 24 hours, which constituted one cycle. The test was performed for six cycles (12 days) [22], [26]. At the end of each cycle, the formulation was observed for any signs of phase separation. After completing all cycles, further evaluations were carried out, including organoleptic observation, pH measurement, viscosity test, spreadability test, adhesion test, and antioxidant activity of the nanoemulgel.

2.3 Determination of Antioxidant Activity of Chia Seed Oil Nanoemulgel

The antioxidant activity of chia seed oil, nanoemulsion, and nanoemulgel were determined using the DPPH method. They were prepared at concentrations of 100, 200, 300, 400, and 500 ppm. Each solution was diluted with ethanol p.a to a final volume of 5 mL. Subsequently, 2 mL of each solution was taken and mixed with 2 mL of DPPH solution. The mixture was homogenized and incubated for 30 minutes at room temperature. The absorbance was then measured at a wavelength of 517 nm using a UV–Vis spectrophotometer. The same procedure was applied to vitamin C as the positive control. Antioxidant activity was determined by calculating the percentage of inhibition (% inhibition) using the following formula [27].

$$\%inhibition = \frac{A.Blank - A.Sample}{A.Blank} \text{ x } 100\%$$

3 Result and Discussion

Oil-in-water (O/W) nanoemulsions (<200 nm) are systems with significant potential for protecting and delivering sensitive compounds such as chia seed oil. These systems can be prepared using either low-energy or high-energy methods. Nanoemulsions are widely used as delivery systems due to their improved stability and enhanced bioavailability. In this study, Cremophor RH 40 was selected as the surfactant because it belongs to the nonionic surfactant group, which generally exhibits lower irritation potential when applied topically. However, in some nanoemulsion formulations, a relatively high

concentration of surfactant is required to achieve a stable system. If the surfactant concentration is too low, it may result in nanoemulsion instability. Therefore, the use of surfactant alone is often insufficient to effectively reduce the interfacial tension between the oil and water phases. For this reason, a co-surfactant such as PEG 400 is required to assist in further reducing the interfacial tension and facilitating the formation of a stable nanoemulsion system.

The optimization and formulation of the nanoemulsion were carried out using variations in surfactant and co-surfactant concentrations as emulsifying agents as they can significantly affect the physical characteristics and stability of nanoemulsion, with surfactant concentrations of 80%, 70%, and 60%, and co-surfactant concentrations of 10%, 20%, and 30%, while chia seed oil was used as the active ingredient at a concentration of 5% as it showed strong antioxidant activity (IC_{50} = 8,318 ppm).

Table 1 Results of the Physical Characterization and Antioxidant Activity of Nanoemulsions

Evaluation	Parameter	Formula		
		F1	F2	F3
Organoleptic	Transparent	Transparent, slightly viscous, specific odor	Transparent, slightly viscous, specific odor	Transparent, slightly viscous, specific odor
% Transmittance	90 – 100%	99,84± 0,066	99,87± 0,051	99,95± 0,035
Viscocity	10 – 2000 cPa.s	216,76± 1,193 cPa.s	194,16± 1,892 cPa.s	184,93± 0,650 cPa.s
pH	4,5 – 6,5	6,176± 0,0057	5,123± 0,0115	4,936± 0,0115
Particle size	5 – 100 nm	17,9 nm	18,3 nm	18,6 nm
Polydispersity index	<0,5	0,111	0,124	0,130
IC_{50}		12,571± 0,1766	13,252± 0,2922	25,693± 0,0873

The organoleptic test was conducted by observing the color, odor, and texture of the nanoemulsion formulations. Based on Table 1, all nanoemulsion formulas exhibited a clear appearance and a strong characteristic odor of chia seed oil. The three formulations showed differences in texture consistency, which were influenced by variations in the concentration of the emulsifying agents. An increase in the concentration of the surfactant Cremophor RH40 resulted in a higher viscosity of the nanoemulsion formulations .

The pH test was conducted to ensure that the nanoemulsion formulations were within the appropriate pH range for skin application, which is between 4.5 and 6.5. Based on Table 1, the pH values of all nanoemulsion formulations fell within the acceptable skin pH range. Formulations with excessively acidic pH may cause skin irritation, while those with overly alkaline pH may lead to skin dryness scaly due to disruption of the acid mantle in the stratum corneum [28]. The pH measurements also showed that higher concentrations of Cremophor RH40 resulted in higher pH values of the nanoemulsion. This occurs because the pH of Cremophor RH 40 tends to be more neutral to slightly alkaline (6.0–7.5) compared to PEG 400, which tends to be slightly more acidic (5.0–7.0).

The viscosity test is an important parameter that reflects the consistency and thickness of nanoemulsion formulations. Higher viscosity indicates a thicker formulation consistency. The acceptable viscosity range for nanoemulsions is 10–2000 cPa·s. Based on Table 1, all formulations met the acceptable viscosity parameters. The viscosity test results indicated that variations in the concentration of the emulsifying agents produced differences in the viscosity of the nanoemulsion formulations. The increase in viscosity associated with higher surfactant concentrations is likely due to interactions between the

hydrophilic groups of Cremophor RH40 and water as the continuous phase through hydrogen bonding, resulting in the formation of a stronger cross-linked structure [14]. In addition, Cremophor RH40 has a higher viscosity than PEG 400 due to its larger and more complex molecular structure as a hydrogenated castor oil derivative with polyoxyethylene chains. The viscosity of Cremophor RH40 is reported to be around 400–800 mPa·s at 25 °C, whereas PEG 400 has a lower viscosity of approximately 90–110 mPa·s at 25 °C. Therefore, increasing the concentration of Cremophor RH40 in the nanoemulsion system can lead to an increase in the viscosity of the formulation.

The clarity of the nanoemulsion formulation was evaluated using the % transmittance test. The percentage of transmittance was measured to ensure the clarity of the nanoemulsion preparation based on visual observation, with distilled water used as the reference. Based on the % transmittance test, all nanoemulsion formulations exhibited a clear and transparent appearance, as indicated by transmittance values ranging from 90–100%. A higher transmittance value indicates that the formulation becomes clearer, suggesting a more homogeneous droplet size distribution. The formation of a nanoemulsion is generally characterized by a clear formulation; therefore, higher clarity values indicate a better nanoemulsion system [29].

The droplet size results of the nanoemulsion formulations were 17.9 nm for F1, 18.3 nm for F2, and 18.6 nm for F3. The droplet sizes of all three formulations met the required range of 10–200 nm. The droplet size of nanoemulsions is also influenced by the concentration of surfactants. In this study, F1, which contained the highest concentration of Cremophor RH40, produced the smallest droplet size. Surfactants act as emulsifying agents that reduce the free energy required for emulsification by lowering the interfacial tension in oil-in-water systems. As the surfactant concentration increases, more surfactant molecules are arranged at the oil–water droplet interface, thereby reducing interfacial tension. Lower interfacial tension facilitates the breakdown of oil droplets during the emulsification process, resulting in the formation of smaller droplets. In addition, surfactants form a monomolecular film layer on the surface of droplets in the oil-in-water nanoemulsion system, which helps prevent the droplets from coalescing within the dispersion medium [30].

In this study, the polydispersity index (PDI) of F1 showed the lowest value at 0.111; however, all three formulations had PDI values below 0.5. The PDI provides information regarding the physical stability of the dispersion system and the uniformity of droplet size distribution. An acceptable range of PDI values is between 0 (monodisperse particles) and 0.5 (broad size distribution). A lower PDI value indicates that the dispersion system has better stability over time [30].

Based on the results of the antioxidant activity test, although all nanoemulsion formulations exhibited very strong antioxidant activity ($IC_{50} < 50$ ppm), a decrease in activity was observed compared to pure chia seed oil ($IC_{50} = 8.318$ ppm). This phenomenon may occur because nanoemulsions are very fine mixtures of oil and water designed to protect antioxidant compounds and maintain their stability. However, when antioxidant compounds are encapsulated by surfactants and co-surfactants within the nanoemulsion system, their accessibility to the target molecules to be neutralized (free radicals DPPH) may be partially hindered by the oil layer and the surrounding emulsifying materials. As a result, the interaction between antioxidants and free radicals may occur more slowly, leading to an apparent decrease in antioxidant activity [31].

In this formulation, the use of Cremophor RH40 as a surfactant and PEG 400 as a co-surfactant plays an important role in forming the interfacial film surrounding the oil droplets. Cremophor RH40, a non-ionic surfactant derived from hydrogenated castor oil with polyoxyethylene chains, forms a relatively thick and stable interfacial layer. Meanwhile, PEG 400 acts as a co-surfactant that reduces interfacial tension and increases the flexibility of the interfacial film, allowing the formation of smaller droplets and improving dispersion of the oil phase in the aqueous medium [16]. Although the chia seed oil nanoemulsion showed slightly lower antioxidant activity than pure chia seed oil, the nanoemulsion formulation still offers several important advantages, particularly for topical applications. Nanoemulsions produce very small droplets that increase the surface area and improve dispersion in the aqueous phase

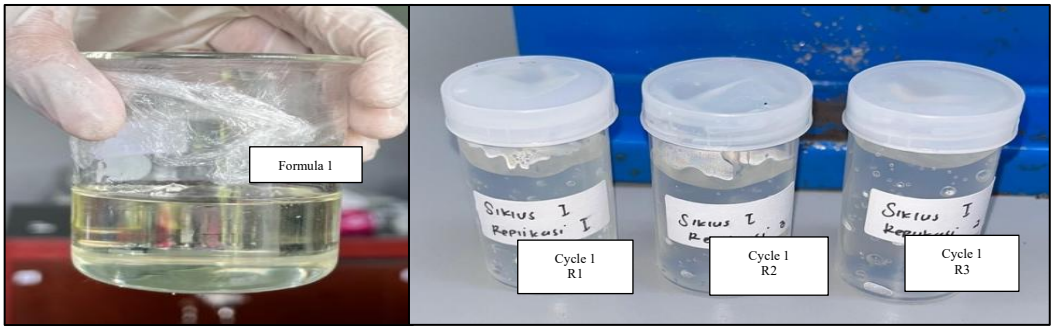
[32]. This is particularly important for topical formulations because pure oils are generally difficult to disperse homogeneously in water-based systems. Furthermore, the small droplet size enhances spreading on the skin surface and increases contact with the stratum corneum, which may improve the deposition and delivery of lipophilic bioactive compounds from chia seed oil into the skin [33]. The interfacial layer formed by the surfactant and co-surfactant can also provide protection against oxidative degradation, thereby improving the stability of bioactive compounds during storage. In addition, nanoemulsion systems may enable a more controlled release of active compounds compared to pure oil [34].

Differences in IC_{50} values may also be influenced by technical factors, such as incubation time and the sample dilution process. Incubation periods that are too short or too long can alter the intensity of the reaction between the sample and DPPH radicals, while inaccuracies in dilution, either in terms of concentration or solution homogeneity, may affect the measured absorbance. In addition, previous research by Julianti (2022) reported that a nanoemulsion of chia seed oil formulated with Tween 80 as the surfactant and sorbitol as the co-surfactant exhibited an IC_{50} value of 2.32 ppm, indicating that differences in the types of emulsifying agents used may also influence the antioxidant activity results [35].

Based on the results of the physical evaluation and antioxidant activity of the nanoemulsion formulations, Formula 1 was selected for further development into a nanoemulgel formulation. The chia seed oil nanoemulgel was prepared by incorporating the nanoemulsion into the gel base. Based on the organoleptic evaluation, the chia seed oil nanoemulgel exhibited a translucent white appearance and a strong characteristic odor of chia seed oil. These characteristics remained stable until the final cycle of the stability test.

Table 2 Results of the Stability Test and Antioxidant Activity of Nanoemulgel

Evaluation	Parameter	Cycle		
		Cycle 0	Cycle 1 – 5	Cycle 6
Organoleptic		Translucent white, slightly viscous, specific odor	Translucent white, slightly viscous, specific odor	Translucent white, slightly viscous, specific odor
Phase Separation	Stable, no phase separation	no phase separation	no phase separation	no phase separation
Homogenity	Homogen	Homogen	Homogen	Homogen
Emulsion type	Oil in water (O/W)	o/w		o/w
Spreadability	5-7 cm	5,766±0,057		5,833±0,0577
Adhesion	No less than 4 seconds	27,666±0,57		21,83±0,5068
pH	4,5 – 6,5	5,236±0,0251		5,83±0,0793
Viscocity	2000-50.000 cPs	46,781±1,625		40,50±0,3946
IC_{50}		22,10 ppm		23,20 ppm



(a) (b)

Figure 1. Organoleptic test result. (a) Nanoemulsion of chia seed oil (Formula 1); (b) Nanoemulgel of chia seed oil. R = Replication.

The organoleptic evaluation was carried out by observing the color, aroma, and texture of the nanoemulgel preparation. Based on Table 2, the formulation exhibited a translucent white color with a strong characteristic aroma of chia seed oil and remained stable from cycle 0 to cycle 6 without any phase separation. As indicated in Table 2, the pH value of the nanoemulgel before the cycling stability test was 5.236, while after the cycling stability test the pH increased to 5.83. During the cycling test process (cycle 1 to cycle 6), an increase in pH was observed due to the influence of temperature variations. The cycling test involved alternating storage at low temperature (4 °C) and high temperature (40 °C), which caused the hydrophilic groups within the formulation to freeze and subsequently melt. This process may alter the chemical equilibrium, leading to ion release or mild degradation that contributes to the increase in pH. Temperature fluctuations may also affect humidity and storage conditions, thereby accelerating overall pH changes [36]. However, the results still met the acceptable pH standards for nanoemulgel formulations.

Similar results were also observed in the viscosity, where changes were noted after cycle 6 compared to cycle 0. This is related to temperature changes that can affect viscosity due to alterations in kinetic energy and the structure of the system. At higher temperatures, the kinetic energy of molecules increases, leading to weaker intermolecular interactions and a looser gel network structure. As a result, the formulation flows more easily and the viscosity decreases. In contrast, at lower temperatures, molecular movement slows down and the gel network structure becomes more compact. This causes the formulation to become thicker, resulting in an increase in viscosity [37]. However, the viscosity and spreadability values of the nanoemulgel formulation still remained within the acceptable standard range for nanoemulgel preparations.

Viscosity has an inverse relationship with the spreadability of nanoemulgel formulations. Viscosity indicates the thickness and flow resistance of a formulation. When the viscosity of a nanoemulgel increases (becomes more viscous), its ability to spread on the skin surface decreases. This occurs because the resistance to flow within the system increases, making the gel more difficult to distribute evenly when pressure is applied. Conversely, nanoemulgels with lower viscosity can flow more easily and spread more readily on the skin surface, resulting in a wider spreading area when a load or pressure is applied [38], [39]. In this study, although changes in spreadability values were observed, they still remained within the acceptable range for a good nanoemulgel formulation.

The adhesion test was conducted to determine the time required for the nanoemulgel to adhere to the skin surface. Good adhesion properties allow the nanoemulgel to remain attached for a longer period, preventing it from easily detaching and enabling the formulation to produce the desired therapeutic effect. The acceptable adhesion time for topical formulations is more than 4 seconds. The results of the adhesion test during the cycling test (cycle 1 to cycle 6) showed a decrease in adhesion time, which was influenced by temperature changes during storage. This phenomenon is similar to the spreadability test, where temperature affects the viscosity of the nanoemulgel. Lower viscosity results in greater spreadability but

reduced adhesion capacity [19], [36]. Nevertheless, the adhesion test results obtained during the cycling test still met the required standard for topical formulations.

The homogeneity test was conducted to ensure that the nanoemulgel formulation had a uniform composition and did not contain coarse particles that could affect user comfort. Good homogeneity ensures that the nanoemulgel is evenly dispersed, making the formulation safe and comfortable for application [40]. The formulation showed good homogeneity, as indicated by a uniform appearance and the absence of coarse particles when spread on a glass slide. Based on Table 2, the nanoemulgel formulation remained homogeneous both before and after the stability test.

Although the antioxidant activity of the chia seed oil nanoemulgel remains very strong, it decreased compared to both pure chia seed oil and the corresponding nanoemulsion formulation. This may occur because the antioxidant compounds are trapped within the oil-phase droplets or the microstructure of the emulgel, so not all active molecules can react with free radicals in the DPPH assay. In addition, interactions with the surfactant, co-surfactant, and the gelling agent may hinder the release of antioxidant compounds [41]. Nevertheless, this behavior may indicate a controlled-release mechanism that is advantageous for prolonged topical protection against oxidative stress. Based on Table 2, there was an increase in the IC_{50} value, indicating a decrease in the antioxidant activity of the nanoemulgel preparation from cycle 0 to cycle 6. The cycling test process (4°C to 40°C) accelerates the degradation of antioxidant compounds through repeated heating, which can damage the chemical structure, such as hydrogen bonds, in the nanoemulgel system. The higher and longer the exposure to temperature, the more active compounds are degraded [42]. However, the antioxidant activity of the nanoemulgel still falls within the strong category.

4 Conclusion

The best nanoemulsion formulation exhibited a droplet size of 17.9 nm, a polydispersity index (PDI) of 0.111, percent transmittance of 99.84%, viscosity of 216.76 cP, and pH of 6.176. In addition, the formulation demonstrated very strong antioxidant activity against DPPH radicals (IC_{50} = 12.571 ppm). The formulation of chia seed oil nanoemulgel consist of 70% nanoemulsion (5% chia seed oil, 80% Cremophor RH 40, and 10% PEG 400) and 30% gel base (0.5% Carbopol 940, 0.5% DMDM hydantoin, and 5% propylene glycol). Results demonstrated that the nanoemulgel possessed good and stable physical characteristics with no phase separation, have very strong antioxidant activity (IC_{50} = 22.10 ppm). This study demonstrates that chia seed oil has the potential to be developed into effective antioxidant cosmetic formulations, highlighting its functional benefits for topical applications. Despite the fact that Indonesia currently relies on imported chia seeds as the primary raw material, the research suggests that value-added products can still be produced through formulation techniques.

5 Declarations

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5.2 Author contributions

Zulhaerana Bahar: Conceptualization, Supervision, Validation, Writing - Review & Editing
Chatrian Dienta: Data Curation, Writing - Review & Editing
Onny Ziasti Fricillia: Writing - Review & Editing
Hanggara Arifian: Data Curation
Viriyanata Wijaya: Data Curation
Wisnu Cahyo Prabowo: Data Curation

5.3 Ethics
The study did not require ethical approval because it did not involve human participants, animals, or identifiable data.

5.4 Conflict of Interest
The authors declare no conflicts of interest during the research and the preparation of this article.

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6 Bibliography
[1] S. G. Tumilaar, A. Hardianto, H. Dohi, and D. Kurnia, 2024. A Comprehensive Review of Free Radicals, Oxidative Stress, and Antioxidants: Overview, Clinical Applications, Global Perspectives, Future Directions, and Mechanisms of Antioxidant Activity of Flavonoid Compounds, J. Chem. Doi: 10.1155/2024/5594386.
[2] P. Chaudhary et al., 2023. Oxidative stress, free radicals and antioxidants: potential crosstalk in the pathophysiology of human diseases, Front. Chem., 11. Doi: 10.3389/fchem.2023.1158198.
[3] N. Chandimali et al., 2025. Free radicals and their impact on health and antioxidant defenses: a review, Cell Death Discov., 11, (1). Doi: 10.1038/s41420-024-02278-8.
[4] B. Mukherjee et al., 2025. Antioxidants and Their Physiological Role in Free Radical Scavenging, Dietary Supplements and Nutraceuticals, pp. 1–44. Doi: 10.1007/978-981-97-9936-7_12-1.
[5] R. A. Trisnadi, 2022. Pengaruh Ekstrak Biji Chia (Salvia Hispanica L.) Terhadap Kadar IL-6, Jurnal Penelitian Kesehatan Suara Forikes, 13, (2).
[6] S. S. Wati, D. A. S. Permana, and Y. Pertiwi, 2025. Senyawa Bioaktif dan Aktivitas Antioksidan Biji Chia (Salvia hispanica L.) Sebagai Pangan Fungsional, Empiricism Journal, 6, (4), pp. 2784–2798. Doi: 10.36312/v7zdrt36.
[7] S. Güzel, M. Ülger, and Y. Özay, 2020. Antimicrobial and Antiproliferative Activities of Chia (Salvia hispanica L.) Seeds, International Journal of Secondary Metabolite, 7, (3), pp. 174–180. Doi: 10.21448/ijsm.722574.
[8] J. Kobus-Cisowska et al., 2019. In vitro screening for acetylcholinesterase and butyrylcholinesterase inhibition and antimicrobial activity of chia seeds (Salvia hispanica L.), Electronic Journal of Biotechnology, 37, pp. 1–10. Doi: 10.1016/j.ejbt.2018.10.002.
[9] Y. Shen et al., 2018. Phytochemical and biological characteristics of Mexican chia seed oil, Molecules, 23, (1)2. Doi: 10.3390/molecules23123219.
[10] S. S. Fernandes, M. B. Egea, M. de las M. Salas-Mellado, and M. R. Segura-Campos, 2023. Chia Oil and Mucilage Nanoemulsion: Potential Strategy to Protect a Functional Ingredient, 2023, Multidisciplinary Digital Publishing Institute (MDPI). Doi: 10.3390/ijms24087384.
[11] D. V. Kuznetcova et al., 2020. Nanoliposomes and nanoemulsions based on chia seed lipids: Preparation and characterization, Int. J. Mol. Sci., 21, (23), pp. 1–15. Doi: 10.3390/ijms21239079.
[12] A. P. Az-Zahra, F. T. Wijayanti, L. Ramadhanti, and I. A. Faizal, 2022. Formulation and Evaluation Of Eel Fish Oil Nanoemulsion Using Sonication Method, Jurnal Pharmaqueous, 4, (2).
[13] B. Iskandar, 2026. Revolusi Kosmetika Topikal Melalui Formulasi Nanogel dan Nanoemulgel: Review Artikel, Majalah Farmasetika, 11, (1). Doi: 10.24198/mfarmasetika.v11i1.68173.
[14] [14] F. Lutfiani Fayakun and M. Prihantini, 2023. Optimasi Konsentrasi Surfaktan Cremophor Rh 40 dalam Nanoemulsi Kompleks Molekular Asam Glikolat-Kitosan Menggunakan Metode Multilevel Categoric-One Factor, Jurnal Ilmu Farmasi dan Farmasi Klinik (JIFFK), 20, (2), pp. 167–175.

[15] [15] T. A. Sari, A. C. Adi, and H. Rachmawati, 2024. Development of nanoemulgel containing nanobentonite-purified catfish oil for candidate of a wound healing dosage form, J. Appl. Pharm. Sci., 14, (7), pp. 184–193. Doi: 10.7324/JAPS.2024.166275.
[16] [16] Y. Syukri, Z. Kholidah, and L. Chabib, 2020. Fabrikasi dan Studi Stabilitas Self-Nano Emulsifying Propolis menggunakan Minyak Kesturi sebagai Pembawa, Jurnal Sains Farmasi & Klinis, 6, (3). Doi: 10.25077/jsfk.6.3.265-273.2019.
[17] [17] Y. Syukri, Z. Kholidah, and L. Chabib, 2020. Fabrikasi dan Studi Stabilitas Self-Nano Emulsifying Propolis menggunakan Minyak Kesturi sebagai Pembawa, Jurnal Sains Farmasi & Klinis, 6, (3). Doi: 10.25077/jsfk.6.3.265-273.2019.
[18] [18] A. C. Adi, N. Setiawaty, A. L. Anindya, and H. Rachmawati, 2019. Formulasi dan Karakterisasi Sediaan Nanoemulsi Vitamin A, Media Gizi Indonesia, 14, (1), pp. 1–13. Doi: 10.204736/mgi.v14i1.1-13.
[19] [19] R. Tungadi, N. A. Thomas, H. Hasan, M. Taupik, and J. J. Pakaya, 2024. Uji Permeasi Nanoemulgel Kurkumin secara In Vitro, Jurnal Farmasi Teknologi Sediaan dan Kosmetika, 1, (3), pp. 91–103. Doi: 10.70075/jftsk.v1i3.20.
[20] D. Andriani, M. Saiful Amin, 2023. Formulasi Nanoemulgel Minyak Atsiri Palmarosa (Cymbopogon Martinii) dan Aktivitas Antiinflamasinya, Cendekia Journal of Pharmacy, 7, (2).
[21] A. Indalifiany, M. Hajrul Malaka, A. Fristiohady, R. Andriani, and M. Harul Malaka, 2021. Formulasi Dan Uji Stabilitas Fisik Nanoemulgel Ekstrak Etanol Spons (Petrosia Sp.), Jurnal Farmasi Sains dan Praktis, 7, (3).
[22] L. Nurdianti, R. Clara, H. Suhendy, F. Setiawan, and K. Idacahyati, 2021. Formulation, Characterization, And Determination Of The Diffusion Rate Study Of Antioxidant Serum Containing Astaxanthin Nanoemulsion, International Journal of Applied Pharmaceutics, 13, (4), pp. 200–204. Doi: 10.22159/IJAP.2021.V13S4.43859.
[23] N. A. Thomas, R. Tungadi, F. Hiola, and M. S. Latif, 2023. Pengaruh Konsentrasi Carbopol 940 Sebagai Gelling Agent Terhadap Stabilitas Fisik Sediaan Gel Lidah Buaya (Aloe Vera), Indonesian Journal of Pharmaceutical Education, 3, (2). Doi: 10.37311/ijpe.v3i2.18050.
[24] S. Z. Munawiroh, F. S. Handayani, and B. H. Nugroh, 2020. Optimasi Formulasi Nanoemulsi Minyak Biji Anggur Energi Tinggi dengan Box Behnken Design (BBD), Majalah Farmasetika. Doi: 10.24198/mfarmasetika.v4i0.25864.
[25] M. Rahmayanti, G. P. Nastiti, and M. A. Fitri, 2023. Formulasi dan Uji Stabilitas Sediaan Hair Emulsion Minyak Biji Chia (Salvia hispanica L.) dengan Kombinasi Tween 80 dan Span 80 sebagai Emulgator, Jurnal Mandala Pharmacon Indonesia, 9, (1), pp. 10–19. Doi: 10.35311/jmpi.v9i1.356.
[26] S. Andini, Yulianita, and E. N. K. Febriani, 2023. Formulasi Sediaan Nanoemulgel Ekstrak Buah Lada Hitam (Piper ningrum L.) dengan Variasi Konsentrasi Tween 80 dan PEG 400, Majalah Farmasetika, 8, (3), pp. 250–6.
[27] S. Hidayati, A. Masykuroh, A. Farmasi, and Y. Pontianak, 2023. Uji Aktivitas Antioksidan Ekstrak Etanol Bunga Pulutan (Urena Lobata L.) Menggunakan Metode DPPH, Jurnal Komunitas Farmasi Nasional, 3, (1).
[28] M. C. Eryani, H. B. H. F. Siddiq, D. Rashati, and R. K. Safitri, 2023. Pengaruh Variasi Konsentrasi HPMC terhadap Sifat Fisik Gel Ekstrak Kulit Pisang Agung Semeru (Musa paradisiaca L.), Jurnal Riset Kefarmasian Indonesia, 5, (1), pp. 12–23.
[29] R. N. Ma'rifah, Masfufatun, and A. F. Listyawati, 2025. Formulasi Dan Evaluasi Nanoemulsi Ekstrak Daun Cengkeh (Syzygium aromaticum), Prosiding Seminar Nasional Kusuma IV, 3, pp. 3062–9365.
[30] L. A. Redhita, M. U. Beandrade, I. K. Putri, and R. Anindita, 2022. Formulasi dan Evaluasi Nanoemulsi Ekstrak Daun Kemangi (Ocimum basilicum L.) dengan Variasi Konsentrasi Tween 80, Jurnal Mitra Kesehatan, 4, (2), pp. 80–91. Doi: 10.47522/jmk.v4i2.134.
[31] N. Fitri, A. A. Tanjungsari, S. K. Himmi, and N. N. Solihat, 2024. Formulation of Nanoemulsion of Gotu Kola (Centella asiatica (L.) Urban) Leaves Extract as Active Ingredients to Produce

Antioxidant Facial Serum, EKSAKTA: Journal of Sciences and Data Analysis, pp. 84–95. Doi: 10.20885/eksakta.vol5.iss1.art10.
[32] E. Deveci, 2025. Nanoemulsions in cosmetics: Enhancing efficacy and stability, KeAi Publishing Communications Ltd. Doi: 10.1016/j.jdsct.2025.100107.
[33] T. L. M. da Silva, A. C. M. de Oliveira Capote, F. L. Beltrame, and P. C. Ferrari, 2026. Nanoemulsions for Skin Delivery of Essential Oils: A Systematic Review, John Wiley and Sons Ltd. Doi: 10.1002/ptr.70184.
[34] S. Ravi, S. Ponnusamy, S. Balakrishnan, N. Karuppusamy, S. Bheeman, and Y. Senthilkumar, 2025. Formulation and Evaluation of Nanoemulsion for Topical Application, J. Neonatal Surg., 14, (32s), pp. 2803–2809.
[35] A. Fadda, M. Serra, M. G. Molinu, E. Azara, A. Barberis, and D. Sanna, 2014. Reaction time and DPPH concentration influence antioxidant activity and kinetic parameters of bioactive molecules and plant extracts in the reaction with the DPPH radical, Journal of Food Composition and Analysis, 35, (2), pp. 112–119.
[36] N. Lumentut, H. J. Edy, and E. M. Rumondora, 2020. Formulasi dan Uji Stabilitas Fisik Sediaan Krim Ekstrak Etanol Kulit Buah Pisang Goroho (Musa acuminafe L.) Konsentrasi 12.5% sebagai Tabir Surya, Jurnal MIPA, 9, pp. 42–46.
[37] R. Wahyuningrum et al., 2025. Review Artikel: Viskositas Sediaan Farmasi (Emulsi, Suspensi, Krim, Gel, Pasta), Jurnal Kolaboratif Sains, 8, (12), pp. 8011–8019. Doi: 10.56338/jks.v8i12.9554.
[38] R. Roro Karina Pambudi and R. Ariastuti, 2023. Formulasi Nanoemulgel Ekstrak Biji Kopi Robusta (Coffea canephora Pierre) dengan Variasi Gelling Agent sebagai Antioksidan, Jurnal Farmasi Indonesia, 20, (1).
[39] T. Imanto, R. Prasetiawan, and E. R. Wikantyasning, 2019. Formulasi dan Karakterisasi Sediaan Nanoemulgel Serbuk Lidah Buaya (Aloe Vera L.), Pharmacon: Jurnal Farmasi Indonesia, 16, (1), pp. 28–37.
[40] R. Hidayati, N. F. Muzdalifah, and G. P. Yudanti, 2025. Variasi Konsentrasi Karbopol 940 pada Formulasi Nanoemulgel Ekstrak Etanol 96% Daun Jambu Biji (Psidium Guajava L.), Jurnal Kajian Ilmiah Kesehatan dan Teknologi, 7, (1), pp. 108–118.
[41] M. M. Suminar and M. Jufri, 2017. Physical stability and antioxidant activity assay of a nanoemulsion gel formulation containing tocotrienol, International Journal of Applied Pharmaceutics, 9, pp. 140–143. Doi: 10.22159/ijap.2017.v9s1.74_81.
[42] M. Prihantini, D. Novianto Wibowo, N. Azizah, and N. F. Setya, 2021. Formulasi Dan Uji Stabilitas Antioksidan Krim Nanopartikel Kitosan-Ekstrak Etanol Daun Sirsak (Annona muricata L.) Menggunakan Metode Cycling Test, Jurnal Ilmiah Cendekia Eksakta, 2, pp. 88–2.