

Effect of Carbopol and Triethanolamine Concentrations on the Physical Stability of *Magnolia alba* Oil Nanoemulgel

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ABSTRACT

Background: *Magnolia alba* (*M.alba*) oil contains bioactive which exhibit antioxidant and antibacterial activities. To optimize its potential for topical application, *M.alba* oil was formulated into self-nanoemulsifying drug delivery system (SNEDDS) and subsequently incorporated into a gel base to enhance user comfort and prolong the residence time of the formulation on the skin. The study aimed to developed and evaluate the physical stability of nanoemulgel *M.alba* oil by examining the effect of varying concentrations of carbopol and triethanolamine (TEA).

Subjects and Method: The nanoemulgel was prepared into four formulations with variation of carbopol (FI 0.5% and FII 1.5%) and TEA (FIII 0.6% and FIV 1.6%). The nanoemulgel were evaluated for organoleptic, homogeneity, pH, adhesion, and spreadability test. The physical stability was assessed using a cycling test under alternating temperature conditions. All data were analyzed statistically at a 95% confidence level.

Results: The evaluation results showed that formulation generally exhibit good physical properties with acceptable range for topical formulation. The variations of carbopol significantly affected the physical quality parameters, particularly pH, adhesion, and spreadability ($p < 0.05$), whereas variations in TEA showed no significant effect. Increasing carbopol concentration enhance the consistency and adhesion, while higher TEA tended to wider the spreadability of the nanoemulgel. Stability testing demonstrated that the nanoemulgel remained generally stable, with minor changes observed in organoleptic properties of FII and slight pH increase significantly in FI.

Conclusion: The developed nanoemulgel exhibited favorable physicochemical properties and acceptable stability with variation of carbopol and TEA. Formulations containing 1% of carbopol with 0.6% and 1.6% TEA showed optimal physical characteristics and stability.

Keywords: carbopol, *Magnolia alba*, nanoemulgel, physical stability, triethanolamine

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BACKGROUND

White champaca (*Magnolia alba*) is a tropical evergreen plant characterized by its distinctive aroma properties. In Bali culture, the fragrance of its flowers is extensively applied in religious rituals, as well as in the production of aromatherapy agents, essential oils, and incense. Its unique aroma is commonly used in religious ceremonies, aromatherapy, essential oils, and incense. Beyond these traditional applications, white champaca flowers also have pharmacological effect, exhibit potential antibacterial, antifungal, antidiabetic, anti-inflammatory, antioxidant, and antidepressant properties (Cheng et al., 2022; Munira et al., 2021; Nayaka et al., 2022; Mendra et al., 2023; Mendra et al., 2024; Mendra et al., 2026). Almost all parts of the flowers can yield essential oils, dominated by linalool, Cyclopentaneacetic acid, 3-oxo-2-pentyl-, methyl ester, Benzyl alcohol, and Phenylethyl alcohol (Ha et al., 2018; Nayaka et al., 2022). Linalool contributes to the characteristics fragrance of fruit, spices, and flowers (Xia et al., 2010). Champaca flower oil inhibits hydrogen peroxide, showing that a 200 mg/mL concentration can suppress up to 60% hydrogen peroxide (Batchu et al., 2017). Antioxidants play an active role in promoting skin health by reducing the risk of premature aging, protecting against reactive oxygen species (ROS) produced by oxidative stress, and shielding the skin from UV radiation (Supriatna et al., 2023).

Given this potential, champaca oil can be developed into a topical preparation that serves as antioxidant agents. Since champaca oil is lipophilic, direct application to the skin may cause greasiness and discomfort, and it is also easily oxidized and prone to rancidity. To enhance the performance of the champaca flower oil, it is suitable for formulation in oil-based delivery

systems with efficient release properties, such as the Self-Nanoemulsifying Drug Delivery System (SNEDDS). For the topical applications, SNEDDS should be incorporated into a gel formulations to improve the adhesion to the skin and ensure better compatibility with the lipid bilayer structure of the skin (Bakri, Sinala & Ratnah, 2023).

An important parameter of a nanoemulgel formulation is its ability to enable drug penetration into the skin, where the active ingredients must be easily released from the base. Therefore, the preparation requires optimal viscosity and adhesion properties. To achieve this, an additional component that enhances viscosity, commonly known as gelling agent. In this study, carbopol was selected as the gelling agent due to its hydrophilic properties, which allows it to disperse easily in water. Carbopol can swell and develop the desired viscosity of the nanoemulgel at a specific pH; therefore, the addition of triethanolamine (TEA) as an alkalizing agent helps to increase the pH of carbopol (Rowe et al., 2020).

The combination of carbopol (1%, 1.5%, 2%) and TEA (1.1%, 0.6%, 0.1%) revealed that the formulation containing 1% carbopol and 1.1% TEA exhibited the optimal adhesion time of 6.14 seconds and achieved a pH value of 5.85. The adhesion characteristic is directly proportional to its viscosity, the higher viscosity results in stronger adhesion in nanoemulgel, leading to more optimal active ingredients penetration into the skin (Thomas et al., 2023). A study by Imanto et al. (2019), using carbopol at various concentrations (0.5%, 1%, 1.5%, 2%) combined with 0.6% TEA, showed that the formulation that containing 1.5% carbopol exhibited good stability, with its viscosity remaining relatively constant during storage at elevated

temperatures compared to other formulations. Another study that combined carbopol (0.5%, 1%, 1.5%, 2%) and TEA (1%, 1.5%, 2%, 2.5%) found that the formulation containing 1% carbopol and 1.5% TEA demonstrated the most stable viscosity (40 Pa.s) and a pH of 6.8 (Handayani, Mita & Ibrahim, 2015). The increasing of carbopol concentration and TEA was found to affect both the adhesion and pH of the formula, where higher concentration led to higher adhesion and pH values (Safitri et al., 2021).

To ensure the stability, in addition to the use of carbopol and TEA, a cycling test is required. This method is chosen because it can stimulate fluctuating storage conditions, providing insights into the durability and physical changes of the nanoemulgel under different temperatures over a specific time interval (Shintyawati et al., 2024). Based on these considerations, SNEDDS was formulated into a nanoemulgel with variations in carbopol as the gelling agent and TEA as the alkalizing agent. The study aimed to investigate the effect of varying concentration of carbopol and TEA on the physical stability of the nanoemulgel which containing *M.alba* oil. The physical quality test including the evaluation of organoleptic, homogeneity, pH, spreadability and adhesion test before and after the exposure to fluctuation temperature during the cycling test.

SUBJECTS AND METHOD

1. Study Design

This study employed an experimental laboratory design to investigate the effects of variations concentration of carbopol and triethanolamine on the physical stability of *Magnolia alba* oil nanoemulgel.

2. Materials

M.alba oil (MAO) were purchased from Botanica Asri (Surabaya, Indonesia), virgin

coconut oil (VCO), tween 80, PEG 400 (Bratachem, Indonesia), distilled water, carbopol 940, triethanolamin (TEA), methyl paraben, propyl paraben, and propylene glycol (SABA, Indonesia).

3. SNEDDS MAO formulation

SNEDDS MAO was prepared using a combination of 1 g *M.alba* oil, 4 g tween 80 as surfactant, and 2 g PEG 400 as co-surfactant based on the optimization from previous study. The oil phase and surfactant were homogenized using magnetic stirrer (Thermo scientific) 500 rpm for 30 minutes. The mixture was subjected to sonication using ultrasonic bath (Elmasonic® S40H, Germany) at 55° C for 10 minutes, to form SNEDDS. The characterization test of SNEDDS including droplet size, polydispersity index, and zeta potential (Mendra et al., 2025).

4. The formulation of nanoemulgel *M.alba*

Nanoemulgel was produced using a high-energy method with homogenizer. The preparation of the nanoemulgel involves three stages including the formation of nanoemulsion from SNEDDS, the formulation of gel based, and the incorporation of nanoemulsion into gel base (Aly et al., 2025). The nanoemulgel formula was listed in Table 1. Carbopol 940 was swelling into propylene glycol and dispersed into 15 ml distilled water at 70° C (a). In separate mortar, methyl paraben and propylene glycol were mixed with distilled water and heated on the waterbath to reach 70° C (b). The mixture b was added to mixture a, and homogenized using homogenizer (IKA-Ultra Turax T25, Germany) at 9600 rpm for 5 minutes to form mixture c. TEA was added to mixture c and re-homogenized at 9600 rpm for 15 minutes to form gel based. SNEDDS was emulsified with distilled water and homogenized in the magnetic stirrer at 500 rpm for 10 minutes to form

nanoemulsion. The nanoemulsion was incorporated dropwise into gel based, followed by an additional mixing at 9600 rpm for 15 minutes to form nanoemulgel.

The nanoemulgel stored at room temperature and evaluate the physical stability (Ullah et al., 2023).

Table 1. Formula of Nanoemulgel *M.alba*

Materials	Concentration (%)				Function
	FI	FII	FIII	FIV	
SNEDDS <i>M.alba</i>	9	9	9	9	
Carbopol 940	0.5	1.5	1	1	Gelling agent
TEA	1.1	1.1	0.6	1.6	Alkalizing agent
Propylene glycol	10	10	10	10	Humectant
Methyl paraben	0.18	0.18	0.18	0.18	Preservative
Propyl paraben	0.02	0.02	0.02	0.02	Preservative
Distilled water	Ad 100	Ad 100	Ad 100	Ad 100	Vehicle

5. The Physical Quality Test

The physical quality evaluation of nanoemulgel encompassed organoleptic assessments, homogeneity, pH measurement, adhesion, and spreadability test. The organoleptic test includes color, odor, and consistency (Rinaldi et al., 2021). Homogeneity was evaluated by visually examining the nanoemulgel for the presence of coarse particles, aggregates, or other visible non-uniformities (Buana et al., 2025). The pH measurement were conducted using a calibrated pH meter with buffer solutions of pH 4.00 and 7.00, performed without dilution. The acceptable pH range is established between 4.50-8.00 (Gonçalves et al., 2017). The adhesion test conducted by placing 0.5 g sample between two glass plates, applying 500 g for 5 minutes. The glass plates were then placed in the adhesion testing apparatus, and an 80-g load was applied. The time required for two glass plates separated was recorded (Imanto et al., 2019). The spreadability test conducted by placing of 0.5 g sample between two glass plates 20 x 20 cm, applying loads of 50 g, 100 g, and 150 g for 5 minutes, and measure the diameter of the spreaded sample (Mendra et al., 2023). All the tests were performed in triplicate.

6. The Physical Stability Test

The stability test were performed by cycling test, which stored alternately at 4° C and 40° C in a climatic chamber (Mettler, Germany) for a total of six cycles, which each cycle consist of 24 hours at 4°C and 24 hours at 40°C. The physical quality evaluation of nanoemulgel, including organoleptic assessments, homogeneity, pH measurement, adhesion, and spreadability test was conducted before and after the cycling test to determine the optimum formula that able to maintain the physical stability of the preparation after exposure to extreme temperature conditions. The formulation was considered physically stable when no statistically significant differences were observed in pH, adhesion, and spreadability between the measurements taken before and after cycling test ($p > 0.05$), with no observable changes in organoleptic properties and homogeneity.

7. Data Analysis

Qualitative data including organoleptic and homogeneity were analyzed descriptively. Quantitative data of physical evaluation including pH, adhesion, and spreadability were expressed as mean and standard deviation. The effects of carbopol and triethanolamine concentration for each

group on the physical quality parameters were analyzed using independent t-test. The changes in pH, adhesion, and spreadability before and after the cycling test were analyzed using paired t-test at a confidence level of 95%.

Table 2. Characterization of SNEDDS MAO

Sample	Droplet size	Zeta potential	Polidispersity index
SNEDDS	16.9 nm	4.42 mV	0.199

The characterization results of the SNEDDS MAO showed a particle size within the nanoparticle size range.

2. The Physical Quality of Nano-emulgel

The physical quality of nanoemulgel MAO including organoleptic characteristics, homogeneity, pH, adhesion, and spreadability test, were summarized in Table 3.

RESULTS

1. Characterization of SNEDDS MAO

The characterization test of SNEDDS including droplet size, zeta potential, and polydispersity index, as detailed in table 2.

The organoleptic assessment involved the examination of consistency, color, and odor of four formula of nanoemulgel preparations. The sample exhibited an emulgel-like consistency with variation viscosity, displaying white color and smell distinctive aroma of white champaca. The macroscopic morphology of the nanoemulgel MAO was depicted in Figure 1.

Table 3. Physical Quality of Nanoemulgel

Test	Detail	FI	FII	FIII	FIV
Organoleptic	Color	White	White	White	White
	Odor	DA	DA	DA	DA
	Consistency	SS (+)	SS (++++)	SS (++++)	SS (++)
Homogeneity		H	H	H	H
pH		7.64 ± 0.01	8.95 ± 0.01	7.46 ± 0.06	7.57 ± 0.10
Adhesion (sec.)		1.41 ± 0.05	2.39 ± 0.26	1.36 ± 0.06	1.19 ± 0.11
Spreadability (cm)		7.4 ± 0.5	4.7 ± 0.1	5.3 ± 0.2	5.6 ± 0.06

Note :

DA : Distinctive aroma of white champaca

SS : semi-solid

+ : low viscosity

++ : slightly viscous

+++ : viscous

++++ : highly viscous

H : Homogen

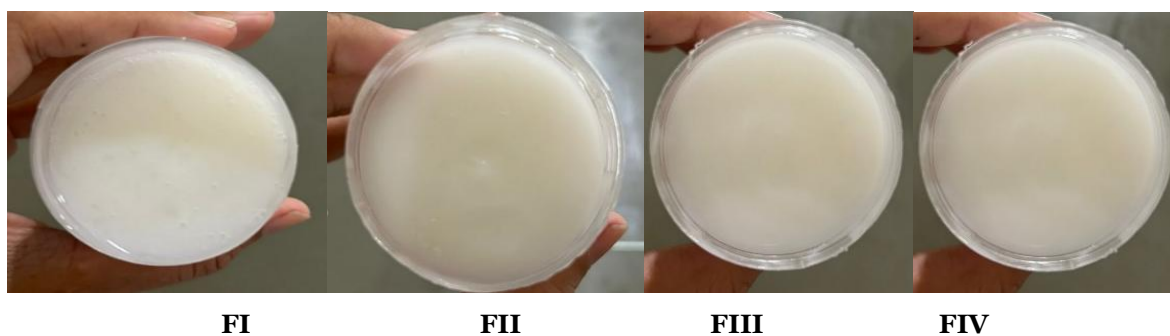


Figure 1. Physical appearance of nanoemulgel MAO

The variation of concentration of carbopol in FI and FII and TEA in FIII and FIV significantly influence the physical quality

of nanoemulgel. The statistic analysis of quantitative data between those formulas were summarized in table 4.

Table 4. The Statistic Analysis of Physical Quality of Nanoemulgel

Comparison	p-value		
	pH	Adhesion	Spreadability
FI vs FII	0.046 ^a	0.003 ^b	<0.001 ^b
FIII vs FIV	0.268 ^a	0.069 ^b	0.067 ^b

Note :

a : Mann-whitney test

b : Independent t-test

3. The Physical Stability of Nano-emulgel

Physical stability testing of the nano-emulgel formulation was evaluated using a cycling test, which the samples were alternately stored at 4° C and 40° C in a

climatic chamber for a total of six cycles. The physical quality were assessed twice, before and after the cycling test to determine the stability of nanoemulgel under extreme temperature conditions. The physical stability were summarized in table 5.

Table 5. Physical Stability of Nanoemulgel

Test	Formula	Before	After	p-value
Organoleptic	FI	White color, DA, SS (+)	White color, DA, SS (+)	-
	FII	White color, DA, SS (++++)	Slightly turbid, DA, SS (++++)	
	FIII	White color, DA, SS (++++)	White color, DA, SS (++++)	
	FIV	White color, DA, SS (++)	White color, DA, SS (++)	
Homogeneity	FI	H	H	-
	FII	H	H	
	FIII	H	H	
	FIV	H	H	
pH (mean; SD)	FI	7.64 (0.01)	7.73 (0.03)	0.023 ^c
	FII	8.95 (0.01)	8.96 (0.03)	0.414 ^c
	FIII	7.46 (0.06)	7.23 (0.07)	0.109 ^d
	FIV	7.57 (0.10)	7.43 (0.02)	0.109 ^d
Adhesion (sec) (mean; SD)	FI	1.41 (0.05)	1.65 (0.21)	0.109 ^d
	FII	2.39 (0.26)	1.79 (0.19)	0.100 ^c
	FIII	1.36 (0.06)	1.37 (0.40)	0.981 ^c
	FIV	1.19 (0.11)	1.28 (0.36)	0.617 ^c
Spreadability (cm) (mean; SD)	FI	7.4 (0.5)	6.80 (0.30)	0.095 ^c
	FII	4.7 (0.1)	4.90 (0.06)	0.180 ^d
	FIII	5.3 (0.2)	5.10 (0.06)	0.317 ^d
	FIV	5.6 (0.06)	5.40 (0.06)	0.102 ^d

Note :

c : Dependent-test

d : Wilcoxon test

RESULTS

Characterization of SNEDDS MAO

The characterization results of the SNEDDS MAO showed a particle size of 16.9 nm, which falls within the nanoparticle size range. This finding indicates that the combination of the oil phase, surfactant, and co-surfactant was appropriate, resulting in the formation of small droplet sizes (Pratiwi et al., 2017; Jacob et al., 2024). In this study, the ratio of surfactants to co-surfactants at 2 : 1, resulting in a hydrophilic-lipophilic balance (HLB) of 14.37, which the optimal HLB for the system is between 12 and 20 (Matsaridou et al., 2012; Costa et al., 2012). Tween 80, due to its higher hydrophilic nature, effectively lowers interfacial tension and stabilizes the emulsion by forming micelle-like structures around the oil droplets. In contrast, PEG 400 improves interfacial packing and further reduces surface energy, thereby inhibiting droplet coalescence (Zhao et al., 2010). In addition, the stirring process facilitates the breakup of larger oil droplets into smaller droplets, whereas sonication plays a crucial role in achieving the targeted final droplet size and uniformity, thereby promoting a monodisperse particle size distribution (Preeti et al., 2023).

Zeta potential measurement is conducted to evaluate the surface charge characteristics of the droplets. Lower zeta potential values indicate reduced colloidal stability, as they promote particle aggregation. In such systems, electrostatic interactions play a crucial role in determining whether nanoparticles undergo aggregation or remain dispersed due to repulsive forces (Preeti et al., 2023). Nevertheless, zeta potential should not be considered the only determinant of SNEDDS stability. In the present study, the relatively low zeta potential value observed may be attributed to the high proportion of non-ionic surfac-

tants used in the formulation (Rachmawati et al., 2015). Low zeta potential values generally indicate diminished colloidal stability, as nanoemulsions are commonly considered stable when the zeta potential exceeds ± 30 mV. Nevertheless, formulations containing non-ionic surfactants, such as Tween 80 and PEG 400, may remain stable due to steric stabilization mechanisms. Unlike ionic surfactants that rely on electrostatic repulsion, non-ionic surfactants form a protective layer surrounding the droplets, which hinders particle aggregation and coalescence, thereby enhancing system stability through steric effects (Singh and Pulikkal, 2022). Therefore, the interpretation and use of zeta potential as the sole indicator of colloidal stability should be treated with caution, as surfactants and the multiple mechanisms governing surface charge and interparticle interactions play a significant role in determining system stability (Zhao et al., 2010; Cortés et al., 2021).

The polydispersity index (PDI) is calculated as the ratio of the standard deviation to the mean particle size and is used to describe the uniformity of droplet size distribution (Miksusanti et al., 2023). Higher PDI values indicate greater heterogeneity and a lower degree of size uniformity among particles (Preeti et al., 2023). Nanoparticles are considered to have a uniform particle size when the PDI within the range of 0.1-0.7. This homogeneity is likely a result of the synergistic effects of Tween 80 and PEG 400 in reducing interfacial tension, thereby enhancing stability by minimizing the risk of aggregation (Sanglyazzahra and Wikantyasning, 2026).

Physical Quality of Nanoemulgel MAO

In this study study, the SNEDDS formulation was incorporated into a gel to form nanomuelgel. Nanoemulgel adhere to the

skin surface, release oil droplets that penetrate the skin and enable to the desired site of action. Moreover, nanoemulgel are considered a promising concept, because of its dual character to enhance the efficient delivery of small droplet size of oil phase with hydrophylic base, which compatible with lipid bilayer structure of the skin (Khan et al., 2024). The use if a gel base provides a cooling and soothing sensation, which is desirable for topical applications. The physical quality of nanoemulgel MAO including organoleptic characteristics, homogeneity, pH, adhesion, and spreadability test.

Organoleptic evaluation was performed visually at room temperature, by observing the color, odor, and consistency of nanoemulgel. The variation of carbopol concentration in formulations FI and FII, as well as differences in TEA in formulations FIII and FIV, did not affect the color and odor of the nanoemulgel, however changes in consistency were observed. An increase in carbopol concentration resulted in a higher consistency of nanoemulgel, as evidenced by FII which exhibited a more compact and viscous texture compared to FI. Homogeneity test was conducted to ensure the component of nanoemulgel were evenly distributed. All four nanoemulgel exhibited good homogeneity, as indicated by the absence of lumps or coarse particles within the formulations. The variation of carbopol significantly affected the physical quality parameters, particularly pH, adhesion, and spreadability ($p < 0.05$), while TEA did not significantly affected. pH evaluation was conducted to ensure the nanoemulgel were compatible with skin pH. An acceptable pH range for the formulation was 4.5-8.0, in accordance with the Indonesia National Standard (SNI) in 1996. Carbopol possesses acidic characteristics; therefore, increasing its concentration is

generally expected to result in a lower pH of the nanoemulgel (Safitri et al., 2021). However, this trend was not observed in formulation FII. In addition to increasing consistency, a higher carbopol concentration also led to an increase pH in FII, compared to FI. This phenomenon may occur because the observed increased in viscosity attributed to the pH-dependent ionization of carbopol. This finding is supported by the consistency result of FII presented in Table 2 and Figure 1, which demonstrate that FII exhibited highly viscous consistency compared with the other formula. This indicated that the increase in pH resulting from the interaction between TEA and carbopol, enhanced the ionization of carboxyl group within the carbopol polymer, thereby leading to an increase consistency (López-Cacho, 2012).

The adhesion test was performed to evaluate the ability of the nanoemulgel to maintain contact with the skin. An increase in carbopol concentration significantly enhance the adhesion of nanoemulgel ($p < 0.05$), whereas an increase in TEA resulted in reduced adhesion. Carbopol 940 was selected as the gelling agent to improve the consistency of the nanoemulgel due to its ease of dispersion in water and its favorable viscosity characteristics. The gelling mechanism of carbopol is attributed to its ability to bind solvent molecules within the polymer structure, leading to polymer cross-linking and subsequent water entrapment, which contributes to gel formation and viscosity enhancement (Safitri et al., 2021).

Combination with propylene glycol played a role in reducing the rigidity of the gel through the formation of hydrogen bonds. It also contributed to maintaining gel viscosity, minimizing water evaporation from the formulation, and preventing

excessive water absorption (Tsabitah et al., 2020; Mendra et al., 2024). Carbopol contains functional hydroxyl and carboxyl groups that exhibit acidic behavior particularly within a pH range of 2.5-4.0. Carbopol remains stable and maintain its viscosity within the pH range of 6-11, and its decrease when the pH falls below 3 or exceeds 12 (Safitri et al., 2021). To achieve the desired pH, the addition of TEA as alkalinizing agent was required. TEA facilitated the ionization of carboxyl groups in carbopol, generating electrostatic repulsion between polymer chains and promoting hydrogen bond formation. These interactions enable polymer to absorb and retain water, leading to an increase viscosity (Safitri et al., 2021; Florence & Attwood, 2005). An increase of TEA concentration in FIV led to a reduction in the viscosity of nanoemulgel, compared to FIII. An excess of TEA interfere hydrogen bond formation between carbopol and water, reducing the ability to retain water. An increase in TEA concentration showed a positive correlation with a decrease of viscosity (Ozon et al., 2025).

This finding was inversely proportional to spreadability, as higher adhesion of the nanoemulgel resulted in lower spreadability. The spreadability test was conducted to evaluate the ability of the nanoemulgel to spread evenly when applied to skin surface. Adequate spreadability is essential to ensure the ease of application and user convenience. An optimal spreadability range for topical formulation is typically between 5-7 cm (Garg et al., 2002).

Physical Stability of Nanoemulgel MAO

Stability is a critical parameter in pharmaceutical formulations, as it ensures that the dosage form remain stable and providing the intended therapeutic effect. The physical

stability of nanoemulgel was evaluated using cycling test. The cycling conditions applied in this study were intended to mimic environmental variations commonly encountered during storing, particularly in tropical regions such as Indonesia, where substantial temperature fluctuations occur between daytime and nighttime, as well as between air-conditioned and warmer storage environments (Mendra et al., 2025). The nanoemulgel was considered stable if it maintained its initial physical characteristic throughout the cycling test period (Aly et al., 2025). The result of stability test indicated that nanoemulgel remain generally stable following the cycling test, with minor alterations observed in the organoleptic properties of FII and pH of FI. The homogeneity evaluation of the nanoemulgel after the cycling test showed no presence of lumps or coarse particles in all formulations.

The organoleptic test of the nanoemulgel showed no differences observed in FI, FIII, and FIV. Formulation FII exhibited a colour change from white to slightly turbid after the cycling test. This alteration may be attributed to temperature-induced physicochemical instability, particularly Ostwald ripening of the nanoemulsion under stress conditions, which promotes gradual growth of larger droplets (Dhyaksa and Jufri, 2021). Elevated temperature increase droplet mobility, thereby enhancing the probability of droplet interaction and coalescence (Zheng et al., 2016). The occurrence of ostwald ripening can lead to the colour change of the nanoemulsion, that consequently affecting the organoleptic properties of nanoemulgel. Based on the previous study, indicates that carbopol generally exhibited weak temperature dependency due to their cross-linked microgel structure, which maintain viscosity stability under thermal fluctuation

(Islam et al., 2004). FII has the highest carbopol concentration among others, which resulted in a more viscous gel network. In highly viscous systems, restricted droplet diffusion and non-uniform redistribution can lead to localized aggregation, resulting in increased turbidity. Thus, the observed colour change in FII is more likely associated with nanoemulsion instability within a stronger gel matrix rather than direct thermal degradation of carbopol.

The result of pH evaluation of nanoemulgel following the cycling test showed insignificant differences changes in FII, FIII, and FIV. Formulation FI showed a statistically significant increase in pH ($\Delta\text{pH} = 0.09$) after the cycling test. This phenomenon may be attributed to its lower carbopol concentration, which provides a reduced acidic buffer capacity. It turns the system are less capable of resisting pH fluctuations during storage or thermal shift, resulting pH elevation. Consequently, the swelling behaviour increases due to the presence of a greater number of carboxylate groups within the polymer network, and increase the adhesiveness (Han et al., 2025). Nevertheless, the observed pH shift remained relatively small and within the acceptable range for topical preparations, indicating that the nanoemulgel maintained acceptable physicochemical stability under stress condition.

The adhesion and spreadability evaluations indicated that the nanoemulgel remained stable, with no statistically significant differences observed before and after the cycling test. Although minor changes in adhesiveness and spreadability were detected, but remained within the acceptable range for topical formulations (Suen et al., 2024).

This study highlights the effect of varying concentration of carbopol and TEA on the physical stability of the nanoemulgel

which containing *M.alba* oil. The nanoemulgel generally demonstrated appropriate physical characteristics for topical application. The stability evaluation through cycling test indicated that the nanoemulgel remained generally stable, with only minor changes observed. Based on the result, FIII and FIV with concentration of carbopol 1 % and TEA 0.6% and 1.6% respectively, exhibited good physical quality, fulfilled the requirements for topical formulation and remained stable following cycling test. Despite this promising result, this study has several limitations. The stability evaluation was limited to thermal cycling stability test, without long-term real-time stability. In addition, in vitro skin permeation and pharmacological activity studies were not performed, which are necessary to confirm the therapeutic performance of developed nanoemulgel. Therefore, future studies involving extended stability testing and in vitro evaluation are recommended to further support the potential application of this nanoemulgel as a tropical drug delivery system.

AUTHORS CONTRIBUTION

Ni Kadek Mira Kusumadewi : study design, execution of formulation and physical quality test, and performed data analysis.

Ni Nyoman Yudianti Mendra : principal investigator, conceptualization, determination of SNEDDS and nanoemulgel formula, performed data analysis, and original manuscript drafting.

Ni Made Dharma Shantini Suen et al. : conceptualization, study design, contributed in physical stability method, review and editing.

Komang Dirga Mega Buana : study design, contributed in SNEDDS formulation, review and editing.

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CONFLICT OF INTEREST

There are no conflicts of interest.

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