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Liniment Formulation with a Combination of Red Palm Oil and Virgin Coconut Oil Base Ingredients

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Abstract

Red palm oil (RPO) is a product that contains high levels of carotene and vitamin E. RPO includes several components such as total carotene, alpha-tocopherol, and tocotrienols, with varying levels of carotene and vitamin E. Vitamin E is essential for maintaining the structural integrity of the skin and is found in the lipid components of the skin. Virgin coconut oil (VCO) is obtained from the fresh coconut kernel without the use of high heat or chemicals. VCO is also used as a liniment because it contains vitamin E and other nutrients. The combination of RPO and VCO was used as a base for liniment formulation with a combination of red palm oil and virgin coconut oil base ingredients. Eight formulas were formulated with various concentrations of RPO and VCO, obtained from Design-Expert software, with the responses being density, pH, and viscosity. The results showed that the combination of RPO and VCO could maintain the stability of the liniment preparation. The optimum formula from the prediction program in Design-Expert was 87.342% RPO and 2.658% VCO.

Keywords: RPO, VCO, Liniment, Design expert.

INTRODUCTION

Red palm oil, also called (Red Palm Oil/RPO), is a source of vegetable oil that grows well in tropical regions. Research shows that red palm oil is very rich in bioactive compounds, including carotenoids (especially beta-carotene) and vitamin E in the form of tocopherols and tocotrienols. Carotenoids that give RPO its red-orange color function as effective antioxidants in counteracting free radicals and support skin health by reducing oxidative damage. Meanwhile, tocopherols and tocotrienols are isomeric forms of vitamin E with high antioxidant properties, protecting cells and tissues from oxidative stress and inflammation. Vitamin E from RPO can maintain skin integrity with its antioxidant properties that prevent skin damage due to exposure to harmful environments and increase skin cell regeneration (Izuddin et al., 2022).

Virgin Coconut Oil (VCO) is oil extracted from fresh coconut meat through a cold-pressing process, which maintains the content of vitamin E, provitamin A, and polyphenols. VCO is known to have various therapeutic properties, including anti-inflammatory, antibacterial, and analgesic effects. Studies have shown that VCO accelerates wound healing, enhances skin regeneration, and protects the skin from free radical damage. In vivo tests have shown that VCO increases wound healing biomarkers in diabetic ulcer rat models, reduces inflammation, and has a protective effect against bacteria such as Staphylococcus aureus by increasing the activity of immune cells in fighting infection. In addition, VCO shows potential to reduce skin inflammation and repair damage caused by environmental exposure, making it a good choice for topical skin care, especially in treating dermatological diseases and as a wound healing agent (Umate et al., 2022).

The manufacture of rubs based on Red Palm Oil (RPO) and Virgin Coconut Oil (VCO) is vital, considering the importance of providing topical skin protection and care. The skin, as the organ most exposed to the external environment—including pollution, UV exposure, and oxidative stress—requires adequate protection to maintain health. The formulation of liniment containing vitamin E from RPO and VCO acts as an antioxidant that protects the skin from cell damage caused by free radicals, helps improve skin regeneration, and reduces inflammation. In addition, this liniment can be used to relieve muscle and joint pain, increase skin moisture, and support wound healing. Given the increasing need for safe and effective skincare products, RPO- and VCO-based liniments are very relevant because they combine the therapeutic properties of these two natural oils, making them a superior choice compared to other products on the market. Thus, this liniment formulation meets skin health needs and contributes to developing safe and effective natural ingredient-based products for skin care (Hendarto, 2022).

Optimization of liniment formula with a combination of Red Palm Oil (RPO) and Virgin Coconut Oil (VCO) as the essential ingredients is an important process in designing effective, efficient, and high-quality pharmaceutical preparations. This study applied the Design of Experiment (DOE) approach to determine the most optimal combination of ingredients. One of the DOE methods used is Simplex Lattice Design (SLD), which allows designing formulations to estimate and predict experimental results mathematically and statistically. This method is beneficial for determining the composition of ingredients in liniment preparations to meet quality parameters such as density, pH, and viscosity, which are important factors in determining the stability and effectiveness of the preparation. In addition, this optimization helps ensure that the resulting liniment preparation is safe and effective and meets the desired therapeutic goals, namely relieving inflammation and improving skin health. Thus, optimization of liniment formulations using the SLD approach not only improves the quality of the preparation but also makes an important contribution to the development of stable and reliable pharmaceutical products (Dwiputri et al., 2022; Hidayat et al., 2020).

Previous studies on liniment optimization have primarily focused on single-oil systems or conventional formulation approaches without systematic statistical modeling. Dwiputri et al. (2022) optimized organic soap formulations combining VCO, palm oil, and olive oil using SLD, demonstrating the effectiveness of mixture design approaches in natural product development. Similarly, Hidayat et al. (2020) highlighted Design-Expert software as a powerful tool for pharmaceutical formulation optimization, enabling systematic exploration of formulation space and prediction of optimal compositions. However, comprehensive optimization studies specifically addressing RPO–VCO combinations in liniment systems remain scarce in the literature. Most existing liniment formulations rely on empirical approaches or single-factor optimization, which may not capture complex synergistic interactions between oil components. Furthermore, while individual therapeutic properties of RPO and VCO have been well-documented, their combined effects in topical liniment formulations have not been systematically investigated using design of experiment methodologies.

The novelty of this study lies in its systematic application of *Simplex Lattice Design* to optimize a binary oil mixture of RPO and VCO for liniment formulation, providing the first comprehensive mathematical modeling of how varying ratios of these two bioactive oils influence critical physicochemical parameters (pH, density, and viscosity) relevant to topical pharmaceutical products. Unlike previous empirical formulation approaches, this research establishes predictive mathematical models that enable precise determination of optimal oil ratios to achieve desired product characteristics, thereby advancing evidence-based formulation development in natural product pharmaceuticals. This approach is particularly significant given the growing demand for scientifically validated natural skincare products and the need for reproducible formulation methods that can be scaled for commercial production.

Therefore, the objectives of this research are threefold: (1) to systematically evaluate the physicochemical properties (pH, density, and viscosity) of liniment formulations containing various ratios of RPO and VCO using *Simplex Lattice Design*; (2) to develop and validate mathematical models that accurately predict the relationship between oil composition and product characteristics; and (3) to determine the optimal combination of RPO and VCO that yields a liniment formulation with physicochemical properties suitable for safe and effective topical application. These objectives address the critical gap in scientifically validated formulation approaches for natural oil-based liniments and provide a methodological framework that can be applied to other multi-component natural product systems.

The practical implications of this research extend beyond academic contributions to pharmaceutical formulation science. The optimized formulation provides a scientifically validated basis for developing commercial liniment products that harness the synergistic therapeutic properties of RPO and VCO, including their combined antioxidant, anti-inflammatory, and skin-regenerative effects. The mathematical models developed in this study enable manufacturers to consistently reproduce formulations with predictable physicochemical characteristics, ensuring product quality and stability. Furthermore, the methodology demonstrates how Design of Experiment approaches can reduce formulation development time and costs while improving product performance compared to traditional trial-and-error methods. This is particularly relevant for small- and medium-scale enterprises in developing countries where both RPO and VCO are readily available natural resources. By establishing clear formulation parameters and quality benchmarks, this research contributes to the standardization of natural product-based pharmaceuticals and supports the development of evidence-based traditional medicine applications.

RESEARCH METHODS

This study was conducted as experimental pharmaceutical formulation research using Simplex Lattice Design (SLD) methodology. Eight liniment formulations were systematically designed using Design-Expert® software version 13 (Stat-Ease, Inc., Minneapolis, USA) to investigate the effects of varying RPO and VCO ratios on physicochemical properties. All experimental measurements were performed in triplicate ($n = 3$) to ensure reproducibility and statistical reliability. The optimization was conducted with a 95% confidence level ($\alpha = 0.05$), meaning that the developed models and predicted optimal formulation have a statistical significance of $p < 0.05$. Response surface methodology was employed to establish mathematical relationships between formulation variables (RPO and VCO concentrations) and measured responses (pH, density, and viscosity). Model adequacy was assessed using analysis of variance (ANOVA), with model terms considered significant when p-values were less than 0.05. The coefficient of determination (R^2) and adjusted R^2 values were used to evaluate model fit quality, with values above 0.80 indicating acceptable predictive capability (David et al., 2020; Sharma et al., 2021).

Regarding safety considerations for topical application, all formulations were designed to meet pharmaceutical standards for dermal products (Schlich et al., 2022; Simoes et al., 2018; Sivaraman & Banga, 2015). The target pH range (4.0–5.8) was selected to be compatible with normal skin pH, minimizing potential irritation and maintaining the skin's acid mantle. Both RPO and VCO are recognized as Generally Recognized as Safe (GRAS) substances for topical use, with well-established safety profiles in cosmetic and pharmaceutical applications. The herbal ingredients incorporated in the formulations (Cinnamomum verum, Curcuma zanthorrhiza, Nigella sativa, Cymbopogon citratus, Andrographis paniculata, Kaempferia galanga, Tinospora cordifolia, and Zingiber officinale) have traditional use histories and documented safety for external application. The manufacturing process employed controlled heating (maximum 80°C for 8 hours) followed by maceration, ensuring that thermolabile bioactive compounds were preserved while achieving adequate extraction. All raw materials were standardized according to Indonesian National Standards (SNI) and international protocols to ensure quality and safety. The optimized formulation's physicochemical parameters (pH, density, and viscosity) were designed to fall within acceptable ranges for topical products, ensuring ease of application, skin compatibility, and product stability during storage.

Ingredients

Red Palm Oil, Virgin Coconut Oil, Olive Oil, Eucalyptus Oil, Cinnamomum verum, Curcuma zanthorrhiza, Nigella sativa, Cymbopogon citratus, Andrographis paniculata, Kaempferia galanga Tinospora cordifolia, Zingiber officinale.

Tools

Analytical Balances, measuring flask, measuring pipette, dropper pipette, beaker glass, stirring rod, spatula, volume pipette, measuring cup, pH meter, Brookfield viscometer, pycnometer

Oil standardization

Oil standardization is carried out using the Iodine Number method (SNI ISO 3961:2015 & SNI 2901:2021 point 7.e), Peroxide Number (SNI ISO 3960:2015 & AOAC 965.33, 2005 & AOAC 965.33, 2005), Water Content (Karl Fischer), Free Fatty Acids (Titrimetry).

Formulation of Liniment

Combine RPO and VCO with other ingredients in a container and heat the mixture to a maximum temperature of 80°C for 8 hours. After heating, allow the mixture to macerate at room temperature for 24 hours, stirring occasionally. Finally, the mixture was filtered using Whatman paper No. 1.

Table 1. Formulation of Liniment Combination RPO and VCO

Composition	concentration	unit
RPO	25-65	mL
VCO	25-65	mL
Olive Oil	5	mL
Eucalyptus Oil	5	mL
Cinnamon	250	Mg
Javanese Turmeric	2	gram
Black Seed	1	gram
Lemon Grass	5	gram
Green Chiretta	800	mg
Aromatic Ginger	2	gram
Tinospora Crispa	2	gram
Ginger	3	gram

Stability and Characterization Tests 6–9

Evaluation of liniment preparations includes organoleptic, pH, viscosity, and Density Tests. Organoleptic tests directly observe color, shape, and odor. pH measurements use a pH meter. The viscosity test procedure is carried out using a Brookville Viscometer. Density tests are carried out to determine the relative density of the liniment, which helps ensure the physical consistency and quality of the preparation. Density test procedures are carried out using a pycnometer. First, the pycnometer is weighed empty, filled with a liniment sample until complete, and reweighed using an analytical balance. Density is calculated by comparing the mass of the sample and the volume occupied by the sample. The parameters used in the density test are density values that must comply with established standards, such as 0.90 gr/mL for edible vegetable oil. This density test is important to ensure that the liniment has the appropriate physical characteristics and is not too thick or liquid.

$$\rho = \frac{m1 - m3}{m2 - m3}$$

Information:
ρ = Density (g/ml)
m1 = mass of pycnometer with massage oil (g)
m2 = mass of pycnometer with aquades (g)
m3 = mass of empty pycnometer (g)

RESULTS AND DISCUSSION

Oil standardization

Iodine Number method

Indonesian National Standard (SNI) 7381:2008 stipulates that the iodine number in Virgin Coconut Oil (VCO) must be in the range of 4.1–11 Wijs oil (SNI, 2008). Meanwhile, the iodine number in Red Palm Oil (RPO) ranges from 51–56. Based on Table 2, the iodine number in VCO is by Indonesian National Standard (SNI) 7381:2008, while the iodine number in RPO is lower than the range reported in previous studies. The iodine number indicates the number of double bonds in the oil, where the double bonds will react with iodine to form saturated compounds. The results of measuring the iodine number in VCO and RPO indicate the presence of unsaturated fatty acids in both oil types, free and bound forms.

Table 2. Oil Standardization Results from RPO and VCO

Parameter	Unit	VCO	RPO
Iodine Number	Wijs	5,64 ± 0,07	50,77 ± 0,34
Peroxide Number	meqO2/kg	Not detected	1,51 ± 0,02
Water Content (Karl Fischer)	%	0,07 ± 0,00	0,14 ± 0,00
Free Fatty Acids	%	0,12 ± 0,00	12,57 ± 0,15

Peroxide Number

Based on Table 2, the peroxide value in VCO was not detected, while the peroxide value in RPO was recorded at 1.51 ± 0.02 meqO_2/kg. The quality of VCO is assessed from the peroxide value because this parameter is an important indicator for determining the level of oil damage. Peroxide is formed due to the reaction of unsaturated fatty acids with oxygen at their double bonds, known as the oxidation process. This process produces oxidation products in compounds with unpleasant aromas and tastes (off-flavor and off-odor), known as rancid. The measured RPO peroxide value was lower than previous studies' results, which was 2.81 meqO_2/kg. This is thought to be related to the natural antioxidant content in RPO. RPO is known to be rich in tocopherols and tocotrienols, two types of powerful antioxidants that play a role in protecting oil from oxidative damage (Marliyati & Harianti, 2021; Tan et al., 2021).

Water Content (Karl Fischer)

The water content of VCO and RPO was recorded at 0.07% and 0.14%, respectively. These values are lower than those required by the National Standardization Agency (BSN) (2006), with a maximum water content of 0.5%. Previous research reported the water content of RPO at 0.04%, while the water content of VCO in this study ranged from 0.90–1.27%. According to AFCC (2005), the water content standard for VCO is 0.1–0.5%. The same standard is also stated in the Indonesian Industrial Standard, where the maximum water content for cooking oil is 0.5%.

The water content in oil significantly affects the quality of the oil produced. This is due to the presence of water, which accelerates the hydrolysis process in oil. the higher the water content in oil, the greater the possibility that the oil will be hydrolyzed into glycerol and free fatty acids (Damin et al., 2021).

Free Fatty Acids

One of the characteristics of Red Palm Oil (RPO) is that it has a free fatty acid (FFA) value of less than 1%. However, in this study, the FFA of RPO was recorded at 12.57%, which is still within the range of previous research results, namely 8.3–14.5%. Meanwhile, the FFA of VCO was recorded at 0.12%, where this value meets the maximum quality standard of 0.2% set by the Indonesian National Standard (SNI) 7381:2008. The FFA levels produced by VCO in this study were by applicable standards, indicating good oil quality. Oil's high free fatty acid content can occur due to improper processing of the triglyceride hydrolysis process. This process can significantly reduce oil quality (De Leonardis et al., 2016).

Evaluation Of Liniment Preparation

Eight formulas selected from the analysis results using Design Expert software with the Simplex Lattice Design method were then evaluated. This preparation was evaluated by comparing the results to two positive controls, products already available on the market, hereinafter referred to as Product X and Product Y (Pramitha et al., 2022; Gunawan, 2019; Fitriani et al., 2016).

Organoleptic

The results of organoleptic observations showed that of the eight formulas tested, the preparation had a greenish-brown color, a distinctive aroma of spices, and the smell of eucalyptus oil. The resulting blur oil showed sediment in varying amounts, which came from the remaining spices that were heated during the manufacturing process.

Table 3. Organoleptic, pH, Density and Viscosity Result Test of Liniment Combination VCO and RPO

Run	Organoleptic	pH	Density	Viscosities (cp)
1	Brownish color, smells of spices, and is typical of eucalyptus oil	5,47 ± 0,01	0,93 ± 0,06	25,60 ± 0,20
2	Brownish color, smells of spices, and is typical of eucalyptus oil	4.18 ± 0,02	0,91 ± 0,01	24,00 ± 0,20
3	Light brownish, has a weaker spice smell and is typical of eucalyptus oil	5,75 ± 0,02	0,91 ± 0,00	20 ± 0,20
4	Light brownish color, smells of spices, and is typical of eucalyptus oil	4,31 ± 0,01	0,94 ± 0,06	18,33 ±0,31
5	Orange in color, smells of spices, and is typical of eucalyptus oil	5,42 ± 0,03	0,91 ± 0,00	22,33 ± 0,31
6	Orange in color, smells of spices, and is typical of eucalyptus oil	5,60 ± 0,01	0,93 ± 0,04	26,00 ± 1,00
7	Greenish brown, smells of spices, and is typical of eucalyptus oil	5,55 ± 0,05	0,87 ± 0,04	14,13±0,31

Run	Organoleptic	pH	Density	Viscosities (cp)
8	Greenish brown, smells of spices, and is typical of eucalyptus oil	5,63 ± 0,05	0,88 ± 0,01	17,13±1,22

pH test

To date, no specific report has stated the ideal pH range for liniments. However, the optimal pH for topical preparations is generally 4 to 5.8, so the pH of the liniment produced in this study can be considered suitable for skin acceptance. The lowest and highest pH values were measured in samples containing 22.5% RPO – 67.5% VCO and 95% VCO, as shown in Figure 1. Although no article has reported the effect of RPO and VCO directly on the pH of the preparation, the mathematical equation used in the software (Stat-Ease, Inc., 2023) allows prediction of the response to certain levels of each factor.

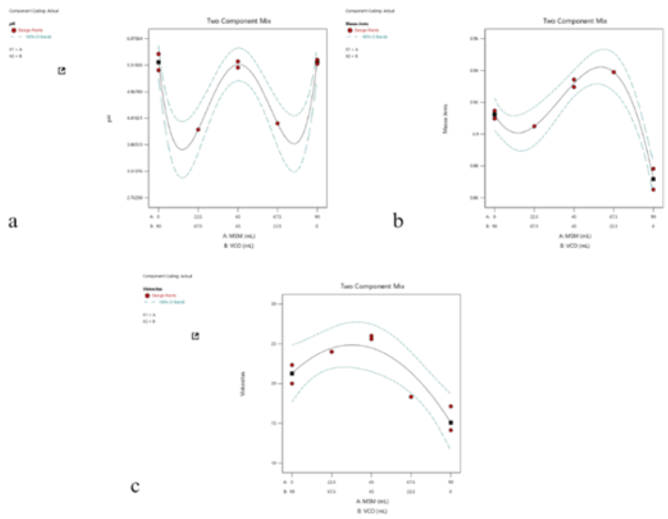

Figure 1 Model Graph of RPO and VCO concentrate on the (a) pH, (b) Vicosity, (c) Density

The pH response modeling is shown in Table 4, where the quartic model is the best model that describes the pH response of the liniment. The model F-value of 28.95 indicates that the model is significant. In other words, there is only a 0.99% chance that an F-value of this size could occur due to disturbance. A P-value of 0.0500 indicates that the term in the model is significant, while a value greater than 0.1000 indicates that the term is not significant. If there are many insignificant model terms (except those needed to support the hierarchical structure), model reduction can help improve the model fit.

Table 4. Predicted model equations of the Liniment responses using the SLD approach

Response	Model	F-value	p-value	R^2	Adj R-squared	Equation
pH	Quartic	28.95	0.0099	0.9747	0.9411	5.59A + 5.59B - 0.2133AB + 0.6756AB(A-B) - 27.80AB(A-B)²
Density	Cubic	57.96	0.0009	0.9775	0.9775	0.8717A + 0.9123B + 0.1600AB + 0.2898AB(A-B)
Viscosity Test	Quadratic	12.81	0,0108	0.8367	0.7714	15.09A+21.27B+25.23AB

Furthermore, Figure 2a shows that the errors are normally distributed, as the normal probability plot of the residuals shows the errors falling on a straight line.

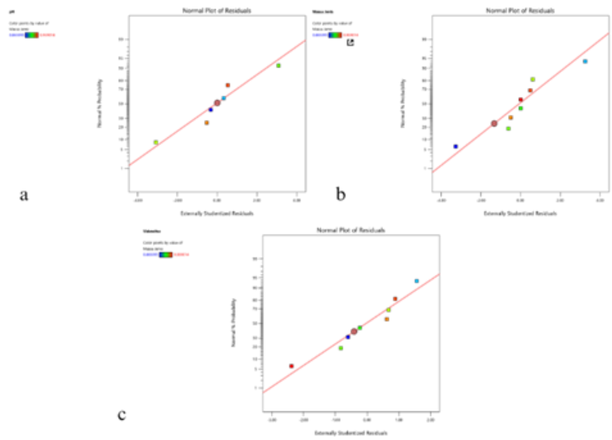

Figure 2. Normal plot of RPO and VCO concentrate on the (a) pH, (b) Vicosity, (c) Density

Density

The highest density value was found in samples containing 67.5% RPO and 22.5% VCO (see Figure 1), while the lowest density value was found in liniment containing 90% RPO. Based on the test results on the eight liniment samples, the results obtained were based on the density standard set by SNI, which is 0.90 gr/mL for edible vegetable oil.

Table 4 shows the density response modelling, with the cubic model being the best model for describing the density response of liniment. The model's F-value of 57.96 indicates that the model is significant. In other words, there is only a 0.09% chance that an F-value of this size can occur due to interference.

A P-value of less than 0.0500 indicates that the terms in the model are significant, while a value greater than 0.1000 indicates that the terms in the model are insignificant. If there are many insignificant model terms (except those needed to support the hierarchy), model reduction can improve the quality of the model. Figure 2b shows that the normality of the density response data indicates that the data is usually distributed and acceptable. This can be seen from the experimental points that are evenly distributed and not far from the linear line.

Viscosity

The highest and lowest viscosities are produced from samples containing 45% RPO – 45% VCO and 90% RPO, respectively (see Figure 1). This is in line with the viscosity of each material listed in Table 5, where the viscosity of RPO is lower than that of VCO. Therefore, liniments with higher RPO content tend to be thinner than those containing more VCO.

Table 5 viscosity result of pure VCO and RPO

	VCO	RPO
Viscosity	34,53 ± 0,31 cp	29,93 ± 0,42 cp

Table 5 shows the viscosity response modeling. The quadratic model is the best model for representing the liniment's viscosity response. The model's F-value is 12.81, indicating that it is significant. The possibility of this F value occurring due to interference is only 1.08%.

A P-value of less than 0.0500 indicates that the model term is significant, while a value greater than 0.1000 indicates that the model term is not significant. If there are many insignificant model terms (except terms needed to support the hierarchy), model reduction can improve the quality of the model.

Furthermore, Figure 2C shows that the normality of the viscosity response data is within an acceptable range. This is indicated by the even distribution of experimental points not far from the linear line.

Determination of Optimum Formula

The pH, density, and viscosity responses are parameters to determine the optimum formula. This determination is done by giving values and weights to each response, as presented in Table 5. The objectives, lower limits, and upper limits of each response in Table 5 are determined based on the requirements for a good liniment preparation.

Table 6. Optimization parameters in determining the optimum formula of Liniment RPO and VCO combination

Parameter	*Goal*	*Lower Limit*	*Upper Limit*	*Importance*
RPO	is in range	0	90	3
VCO	is in range	0	90	3
pH	is in range	4.5	5.5	3
Viscosity	is in range	14.1333	16	3
Density	is in range	0.865095	0.91	3

Based on the optimization results using the numerical method with Design Expert software, the optimum combination of preservatives was obtained: 87.342% RPO and 2.658% VCO with a desirability value of 1,000 (Stat-Ease, Inc., 2023). The desirability value is influenced by the number of responses used and the target to be achieved to obtain the optimum formula (Saryanti et al., 2019).

CONCLUSION

Variations in the concentrate levels of Red Palm Oil (RPO) and Virgin Coconut Oil (VCO) significantly affected the physical properties of the liniment preparation. The optimum formula was achieved with 87.342% RPO and 2.658% VCO, yielding desirable physicochemical characteristics such as pH, density, and viscosity suitable for topical application. For future research, investigators could explore the in vivo efficacy of this optimized RPO-VCO liniment on animal models of skin inflammation or wound healing, or extend the Simplex Lattice Design to incorporate additional natural actives (e.g., essential oils) for enhanced therapeutic profiles. The authors thank the financial support from faculty of pharmacy, Universitas Islam Sultan Agung, Semarang which have supported and funded this research.

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