

Development of Sunscreen Lotion from PKO–VCO with Surfactant Variation and Combined TiO₂ and Palm Leaf Ethanol Extract Actives

Khansa Jihan Safitri¹, Wydia Soffiyah², Alda Nathasya³, Reni Astuti Widyowanti^{4✉}

^{1, 2, 3, 4} Agricultural Product Technology, Faculty of Agricultural Technology, Institut Pertanian STIPER Yogyakarta, Indonesia

✉ **Corresponding Author** : Reni Astuti Widyowanti (e-mail: reniastuti8484@gmail.com)

Article Information	ABSTRACT
Article History Received : May 06, 2026 Revised : May 23, 2026 Published : July 04, 2026	High exposure to ultraviolet radiation in the tropics increases the risk of skin damage, making it necessary to develop an effective and stable sunscreen lotion. This study aimed to analyze the effects of Tween 80:cetyl alcohol surfactant combinations and combined active ingredients of titanium dioxide (TiO ₂) and palm leaf ethanol extract on the physical characteristics and functional activity of PKO- and VCO-based lotions. The study employed a 3×3 factorial Randomized Complete Block Design (RCBD) with two replications, resulting in 18 treatment combinations consisting of variations in surfactant ratios and active ingredient concentrations. Data were analyzed using Analysis of Variance (ANOVA) followed by Duncan's Multiple Range Test (DMRT) at a 5% significance level. The parameters evaluated included viscosity, pH, specific gravity, homogeneity, organoleptic properties, SPF value, and antioxidant activity using the DPPH method. The results showed that surfactants significantly affected viscosity, pH, and specific gravity, while active ingredients significantly influenced SPF value and antioxidant activity. The highest SPF value was obtained in treatment A3B2 with a value of 4.30, which was categorized as minimal protection according to the FDA sunscreen classification, while the highest and lowest antioxidant activities were 95.51% and 87.97%, respectively. All formulations showed good homogeneity and pH values suitable for skin application. Overall, the optimum formulation combination produced lotion with good physical stability, high antioxidant activity, and potential to be developed as a natural sunscreen.
Keywords: <i>Antioxidant Activity;</i> <i>Palm Leaf Extract;</i> <i>Sunscreen Lotion;</i> <i>SPF Value;</i> <i>Physical Stability.</i>	

INTRODUCTION

The cosmetics industry, in particular *Lotion*, it is necessary to adapt to the tropical conditions of Indonesia where the Meteorology, Climatology, and Geophysics Agency notes that the ultraviolet (UV) index ranges from 8-11 which are in the very high to extreme category most of the year, thus increasing the risk of skin damage (BMKG, 2021). This intense UV exposure not only damages the epidermis and reduces skin moisture, but also triggers the formation of free radicals that accelerate premature aging. The importance of this protection is affirmed globally, where *International Agency for Research on Cancer* (International Agency for Research on Cancer, 2025) records more than 1.5 million new skin cancer cases every year, and locally, data from Sanglah Denpasar Hospital shows that skin cancer cases reached around 7% of all cancer cases in the 2015–2018 period (Setiabudi *et al.*, 2021). The high risk, especially in the tropics, reinforces the urgency of developing preparations *Lotion* Effective, safe and stable sunscreen for daily use.

Lotion is a semi-liquid emulsion preparation that is generally in the form of oil in water (*oil in water*, O/W), composed of oil phase, water phase, surfactant, co-emulsifier, and active ingredients.

In formulation *Lotion* Sunscreen, oil phase plays an important role in providing emollient properties and comfort of use, while surfactants function to reduce the interface tension between oil and water to form a stable emulsion. The selection and comparison of surfactants is a crucial factor because it greatly affects physical stability, viscosity, homogeneity, and dispersibility *Lotion* during storage (Sari & Zulkarnain, 2024).

In development *Lotion* based on natural ingredients, *Palm Kernel Oil* (PKO) and *Virgin Coconut Oil* (VCO) is an option that can be used as an oil phase in formulations *Lotion*. PKO contains high lauric acid, while VCO is rich in medium-chain fatty acids that are easily absorbed by the skin, are emollient, and provide a mild sensation. These two ingredients not only function as natural softeners, but also help strengthen the skin's protective layer, retain moisture, and have natural antimicrobial activity through the formation of monolaurin (Amaliyah *et al.*, 2024; Nainggolan & Sinaga, 2024). In addition to having a moisturizing function, the use of PKO and VCO also supports the use of Indonesian tropical commodities because both are abundant plantation processed products.

On the other hand, oil palm plantation biomass such as oil palm leaves is still not optimally utilized and generally only becomes waste. In fact, oil palm leaves contain bioactive compounds in the form of flavonoids, phenolics, tannins, and vitamin E which have antioxidant activity (Zumaro) *et al.*, 2021). These flavonoid and phenolic compounds have chromophore groups that are able to absorb UV radiation and act as free radical trappers, so they have the potential to support sunscreen activities. Some studies report that palm leaf extract has antioxidant activity with IC values₅₀ Approximately 133 ppm, which shows its potential as a natural active ingredient in formulations *Lotion* Sunscreen (Cahya & Fitri, 2020).

In addition to natural antioxidants, protection against UV radiation in preparations *Lotion* generally reinforced by the addition of titanium dioxide (TiO₂) as an inorganic sunscreen that works by the mechanism of reflecting and scattering UV-A and UV-B radiation. In research Rozqiah *et al.* (2023), obtained an increase in TiO concentration₂ and plant bay leaf ethanol extract that has similar flavonoid and phenolic content to oil palm leaves significantly increases the value of *Sun Protection Factor* (SPF) VCO-based sunscreen cream. This shows that there is a synergistic effect between TiO₂ as a physical protector and plant extract as a UV absorber as well as an antioxidant.

Effectiveness of increasing SPF values through a combination of TiO₂ and plant extracts are highly dependent on the stability of the emulsion system *Lotion*, which is determined by the type and ratio of surfactants used. Tween 80 plays a role in forming an oil-in-water emulsion (O/W), while cetyl alcohol acts as a co-emulsifier and thickening agent that strengthens the interface layer and helps in the dispersion of TiO particles₂ Evenly (Setiana, 2018). However, research on VCO-based sunscreen formulations generally still focuses on variations in TiO concentrations₂ or plant extracts as active ingredients, while the role of surfactant systems on the physical stability and characteristics of the preparation is still limited. Therefore, there is a research gap in the formulation *Lotion* vegetable oil-based sunscreen that combines VCO, PKO, palm leaf extract, and TiO₂, especially related to the influence of TiO comparisons₂ and surfactant to stability and characteristics *Lotion*.

This study presents a novel approach by developing a PKO–VCO-based sunscreen lotion containing combined TiO₂ and oil palm leaf ethanol extract as active ingredients with surfactant ratio optimization. Unlike previous studies that mainly evaluated TiO₂ or plant extracts separately in sunscreen formulations, this research integrates PKO, VCO, TiO₂, and oil palm leaf extract in a single emulsion system and investigates their combined effects on the physicochemical characteristics, antioxidant activity, and SPF value of the lotion.

RESEARCH METHODS

This study used a Randomized Complete Block Design (RCBD) with a factorial pattern consisting of two factors and two replications. The first factor was the ratio of surfactants (Tween 80 : cetyl alcohol), namely A1 (3.75 : 1.25), A2 (2.5 : 2.5), and A3 (1.25 : 3.75). The second factor was the ratio of TiO₂ : ethanol extract of oil palm leaves (EEOPL), namely B1 (6 g : 1.5 g), B2 (7 g : 2 g), and B3 (8 g : 2.5 g), resulting in nine treatment combinations. The manufacture of palm

leaf ethanol extract began with fresh, healthy green oil palm leaves (*Elaeis guineensis* Jacq.) which were washed thoroughly, cut into $\pm 3\text{--}5$ cm pieces, and oven-dried at 60°C until constant weight was achieved (Kartiko & Fanani, 2021). The dried leaves were ground into simplicia powder and extracted using the maceration method with 96% ethanol at a ratio of 1:10 (w/v) for 2×24 hours under closed conditions and protected from light. The maceration results were filtered to obtain macerate, then concentrated using a rotary evaporator at temperatures below 50°C until a thick ethanol extract of oil palm leaves was obtained. The extract was stored in a dark glass container at $4\text{--}8^\circ\text{C}$ until used in the lotion formulation (Zumaro et al., 2021).

The manufacture of lotion preparations was carried out by weighing all ingredients according to the predetermined formulation based on treatment combinations. In the oil phase, each treatment used 5 g of CCO, 5 g of PKO, 3 g of stearic acid, and 5 g of glyceryl monostearate, with variations of cetyl alcohol consisting of 1.25 g (A1), 2.5 g (A2), and 3.75 g (A3), as well as titanium dioxide (TiO_2) consisting of 6 g (B1), 7 g (B2), and 8 g (B3), respectively. In the water phase, aquadest was used at 68.5 g (B1), 67 g (B2), and 65.5 g (B3), with Tween 80 consisting of 3.75 g (A1), 2.5 g (A2), and 1.25 g (A3), respectively, while preservatives and fragrances were added at 0.5 g each. Active ingredients in the form of EEOPL were added according to treatment levels, namely 1.5 g (B1), 2 g (B2), and 2.5 g (B3). The oil phase consisting of stearic acid, cetyl alcohol, glyceryl monostearate, titanium dioxide, PKO, and VCO was heated at $\pm 70^\circ\text{C}$ while continuously stirred until homogeneous. Separately, the water phase consisting of Tween 80, preservatives, and aquadest was heated at the same temperature until homogeneous. After both phases reached the same temperature, the oil phase was slowly poured into the water phase while continuously stirred until an emulsion was formed. Homogenization was carried out using a homogenizer at a speed of 1,500–2,000 rpm for 10–15 minutes until a homogeneous lotion preparation was obtained. The mixture was cooled while continuously stirred until it reached a temperature of $\pm 35^\circ\text{C}$, after which EEOPL and fragrance were added gradually and stirred continuously until a stable and homogeneous lotion preparation without phase separation was obtained (Widayasanti et al., 2023).

The parameters observed in this study included organoleptic properties, homogeneity, viscosity, spreadability, pH, specific gravity, antioxidant activity, and Sun Protection Factor (SPF) value. Organoleptic testing was carried out visually by observing the color, aroma, texture, and physical appearance of the lotion preparation, while homogeneity testing was conducted by applying the lotion sample onto a glass slide and observing the presence of coarse particles or phase separation. Viscosity measurements were carried out using a Brookfield viscometer at room temperature ($25 \pm 2^\circ\text{C}$) using spindle number 3 at a constant rotational speed. Spreadability testing was performed by placing 0.5 g of lotion sample between two glass plates followed by gradual addition of loads ranging from 50–250 g, after which the spread diameter was measured. The pH value was determined using a calibrated digital pH meter by diluting 1 g of lotion sample with 10 mL distilled water before measurement, while specific gravity testing was carried out using a pycnometer by comparing the weight of the lotion sample with the weight of distilled water at the same volume (Tranggono & Latifah, 2007). Antioxidant activity was determined using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging method, where absorbance was measured using a UV–Vis spectrophotometer at 517 nm after incubation under dark conditions for 30 minutes, and antioxidant activity was expressed as percentage inhibition (Molyneux, 2004). SPF values were determined using an in vitro UV–Vis spectrophotometric method based on the Mansur equation by measuring absorbance at wavelengths of 290–320 nm with intervals of 5 nm using a UV–Vis spectrophotometer (Mansur et al., 1986). All experimental data were expressed as mean $\pm$ standard deviation and analyzed statistically using Analysis of Variance (ANOVA) at a significance level of 5% ($p < 0.05$) using SPSS software. If significant differences were observed, Duncan's Multiple Range Test (DMRT) was conducted as a post hoc test to compare differences among treatment means.

RESULTS AND DISCUSSION

Table 1. Summary of Physicochemical Characteristics, SPF Value, and Antioxidant Activity of PKO–VCO-Based Sunscreen Lotion Under Different Surfactant and Active Ingredient Treatments

Treat- ment	Viscosity	SPF Lotion Value	pH Lotion	Weight Type Lotion	Antioxidant Activity
A1B1	10615 ± 1354.817	.99268 ± .052561	4.7300 ± .15556	.891200 ± .0101823	87.973000 ± 1.5301791
A1B2	11782 ± 1541.493	.88297 ± .006004	4.7650 ± .16263	.931600 ± .0000000	91.153500 ± .8577205
A1B3	12875.5 ± 1991.920	1.40476 ± .065548	4.7350 ± .21920	.953600 ± .0000000	91.714500 ± .5946768
A2B1	16223.5 ± 5052.278	.80291 ± .064662	4.7750 ± .09192	.952400 ± .0124451	90.217500 ± .4659834
A2B2	17928 ± 3693.926	1.27389 ± .004900	5.1150 ± .26163	.960600 ± .0183848	92.147500 ± 1.6072537
A2B3	21974.5 ± 2530.735	4.22083 ± .032032	5.3500 ± .38184	.998600 ± .0014142	95.326500 ± .2764788
A3B1	32941.5 ± 406.586	.94767 ± .018941	5.4800 ± .36770	1.024600 ± .0008485	92.024500 ± .3740595
A3B2	34686.5 ± 205.768	4.30296 ± .148613	5.5500 ± .36770	1.028200 ± .0098995	95.511000 ± 2.1269772
A3B3	36766 ± 1069.145	2.42254 ± .013479	5.7200 ± .28284	1.092600 ± .0138593	93.768500 ± .7219560

Based on the data presented in Table 1, increasing the proportion of cetyl alcohol in the surfactant system significantly increased lotion viscosity. The treatment with a Tween 80:cetyl alcohol ratio of 3.75:1.25 g showed the lowest average viscosity value of 11757.50 ± 1630.41 cP, while the ratio of 1.25:3.75 g produced the highest viscosity value of 34798.00 ± 1789.68 cP. Duncan's test indicated that each surfactant treatment belonged to different subsets, indicating significant differences among treatments ($p < 0.05$). The increase in viscosity occurred because cetyl alcohol acts as a co-emulsifier and thickening agent capable of strengthening the emulsion structure and enhancing interactions between the oil and water phases.

For the SPF parameter, the highest value was obtained in treatment A3B2 with an SPF value of 4.303, which falls into the minimal protection category according to FDA classification. Meanwhile, the lowest SPF value was observed in treatment A2B1 at 0.803, indicating that it did not yet meet the effective sunscreen category. The increase in SPF value was influenced by the presence of TiO₂ as a physical sunscreen capable of reflecting and scattering UV radiation, as well as flavonoid and phenolic compounds in oil palm leaf ethanol extract that potentially absorb UV radiation.

The antioxidant activity of the lotion showed relatively high values across all treatments, with the highest activity of 95.511% observed in treatment A3B2 and the lowest activity of 87.973% in treatment A1B1. The high antioxidant activity was attributed to bioactive compounds in the oil palm leaf extract, such as flavonoids and phenolics, which are capable of scavenging free radicals. For the pH parameter, all formulations were within the range of 4.730–5.720, which is still suitable for skin application. In addition, the specific gravity values increased with increasing active ingredient concentration, ranging from 0.8912 g/cm³ in treatment A1B1 to 1.0926 g/cm³ in treatment A3B3. Overall, formulations containing

higher concentrations of cetyl alcohol and active ingredients tended to produce lotions with better viscosity, SPF value, and antioxidant activity.

Viscosity

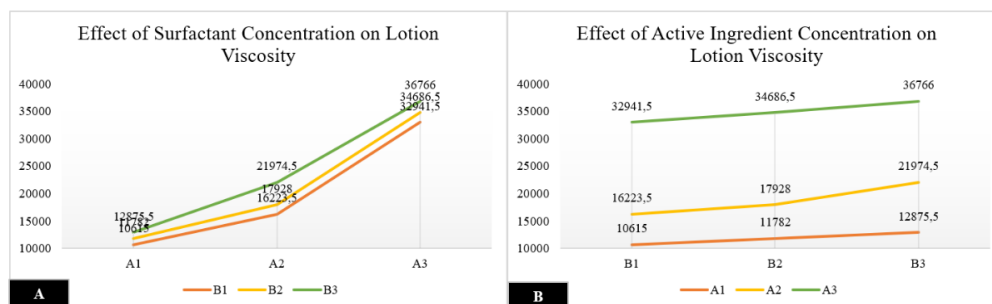


Image 1. Effect of Surfactant (A) and Active Ingredient (B) Concentrations on Sunscreen Lotion Viscosity

Based on Figure 1A, it can be seen that increasing the proportion of cetyl alcohol in the surfactant system from A1 to A3 consistently increases the viscosity of the lotion across the variety of active ingredients. A fairly sharp increase mainly occurred from A2 to A3, with the highest value in combination A3B3 ($\pm 36,766$ cP). The relatively parallel line pattern between B1–B3 shows that the influence of surfactants is dominant over the active ingredient. Mechanistic, cetyl alcohol as a co-emulsifier and thickening agent is able to increase viscosity through the formation of a denser emulsion structure and strengthen the interaction between phases. This is in line with Nurmallasari *et al.*, (2023) and Zhang *et al.*, (2021) which states that an increase in the emulsifier component will result in a more stable and viscous emulsion system. Meanwhile, Figure 1B shows that increasing the concentration of active ingredients from B1 to B3 also increases viscosity, but with a more sloping tendency. This increase is influenced by the presence of TiO_2 as a solid particle that adds to the dispersed phase fraction thereby increasing the viscosity of the system. However, an almost parallel pattern at each surfactant level showed that there was no strong interaction between the two factors, according to the ANOVA results ($p > 0.05$). Thus, the viscosity of the lotion is more determined by the composition of the surfactant, while the active ingredient acts as a supporting factor in increasing the viscosity of the preparation.

pH Lotion

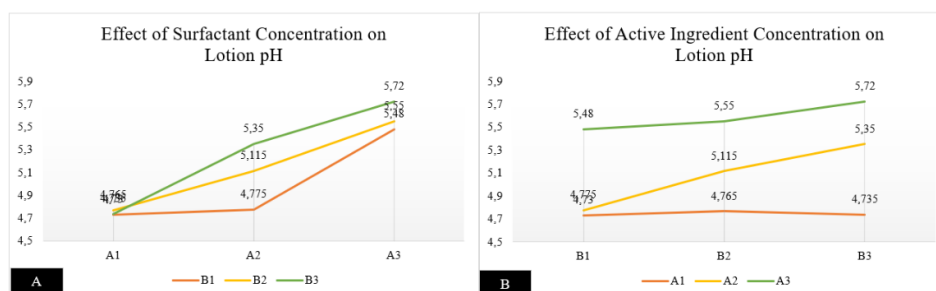


Image 2. Effect of Surfactant (A) and Active Ingredient (B) Concentrations on Sunscreen Lotion pH

Based on Figure 2A, it can be seen that increasing the proportion of cetyl alcohol in the surfactant system consistently increases the pH value of the lotion across the variety of active ingredients. The pH value at A1 is in the more acidic range ($\pm 4,7$), then increases at A2 ($\pm 5,0$ – $5,3$), and achieved the highest score on A3 ($\pm 5,5$ – $5,7$). The relatively parallel line pattern between B1–B3 shows that the influence of surfactants is more dominant than the active ingredient. Mechanistically, the increase in cetyl alcohol as a co-emulsifier affects the balance of the emulsion system and the interaction between the components, thus causing the pH shift to become closer to neutral. This is in line with Squirting *et al.* (2022) and Athiyyah *et al.* (2025) which states that the composition of surfactants can affect the stability and acidity degree of emulsion preparations. Meanwhile, Figure 2B shows that the increase in the concentration of the active ingredient provides only a relatively small increase in pH and tends to be consistent at each surfactant level. This almost parallel pattern shows the absence of strong interaction between factors, which is also

supported by the ANOVA results ($p > 0.05$). Thus, the change in pH of the lotion in this study was more determined by the variation of surfactants, while the active ingredient played a minor factor that did not have a significant effect. All pH values obtained are still within the safe range for topical preparations (± 4.5 – 6.5), so that the resulting formulation still meets the safety and comfort of use aspects (Lukic *et al.*, 2021).

Antioxidant Activity of Lotion

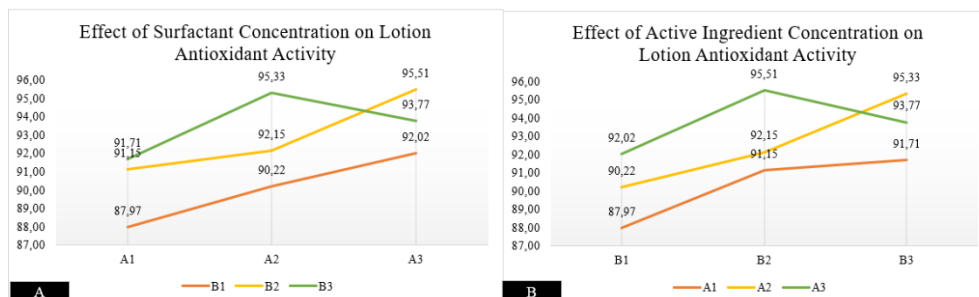


Figure 3. Effect of Surfactant (A) and Active Ingredient (B) Concentrations on Lotion Antioxidant Activity

Based on Figure 3A, it can be seen that an increase in surfactant composition from A1 to A3 tends to be followed by an increase in the antioxidant activity of the lotion across the variety of active ingredients. The value of activity increased from around 87.97% in A1B1 to reach the highest value in A3B2 of 95.51%. This pattern shows that surfactants play a role in increasing the effectiveness of the emulsion system, especially in dispersing EEOPL so that it interacts more optimally with free radicals. According to McClements (2016), The stability and droplet size of emulsions greatly affect the availability of bioactive compounds, so a more stable emulsion system will increase antioxidant activity. In addition, the free radical capture mechanism in the DPPH method occurs through the donation of electrons or hydrogen atoms by phenolic compounds, as described by Brand-Williams *et al.* (1995) and Shahidi & Zhong (2015). Meanwhile, Figure 3B shows that an increase in the concentration of active ingredients from B1 to B3 also increases antioxidant activity, although it does not necessarily provide a significant increase in all conditions. The highest values were found in B2 and B3, which showed that the increased concentration of EEOPL enriched the content of phenolic compounds and flavonoids as electron donors. However, at certain concentrations a plateau tendency is noticeable, which indicates that the system is starting to reach an optimal point so that the addition of active ingredients no longer increases activity significantly. This is in line with Shahidi & Zhong (2015) which states that antioxidant activity has a limit of effectiveness at certain concentrations. Thus, both surfactants and active ingredients contribute to antioxidant activity, but work independently without strong interactions, as the ANOVA results also show.

SPF Lotion Value

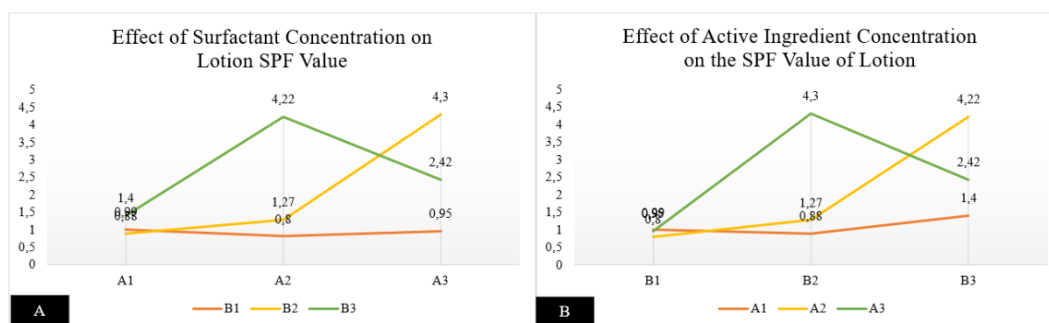


Figure 4. Effect of Surfactant (A) and Active Ingredient (B) Concentrations on SPF Value of Sunscreen Lotion

Based on the graph in Figure 4A, it can be seen that an increase in the proportion of cetyl alcohol tends to increase the SPF value, but the pattern of increase depends on the type of active ingredient. In B1, the change in surfactant ratio did not provide a significant improvement (± 0.80 – 0.99), suggesting that at low concentrations of active ingredients, improvements in the emulsion system have not been sufficient to improve protection effectiveness. In contrast, in B2 and B3 there was a more pronounced spike in SPF, with peaks at A3B2 (4.30) and A2B3 (4.22). This pattern indicates that an increase in cetyl alcohol improves the viscosity and stability of the emulsion so that the dispersion of TiO_2 and EEOPL becomes more homogeneous, but at certain ratios (e.g. A3 to B3) there is a decline again that is suspected to be due to particle aggregation or an increase in excess viscosity that inhibits even distribution.

Meanwhile, in Figure 4B, it can be seen that increased concentrations of active ingredients generally increase SPF values, but the response is not linear at each surfactant ratio. At A1, the increase in SPF is relatively low despite the TiO_2 concentration and EEOPL are enhanced, demonstrating the limitations of its emulsion system. In A2 and A3, the increase in active ingredients provided a significant response, especially in B2 and B3, confirming a strong interaction between the two factors as supported by the results of ANOVA and the Duncan test. Scientifically, TiO_2 acts as a physical sunscreen that reflects UV radiation, while EEOPL contributes antioxidants, but the effectiveness of both is greatly influenced by the ability of surfactants to form a uniform film on the surface of the skin. These findings are in line with Scarlet & Violet (2021) and Wulandari *et al.* (2019) which states that the balance of surfactant and active ingredient composition is key to achieving optimal SPF values.

Weight Type Lotion

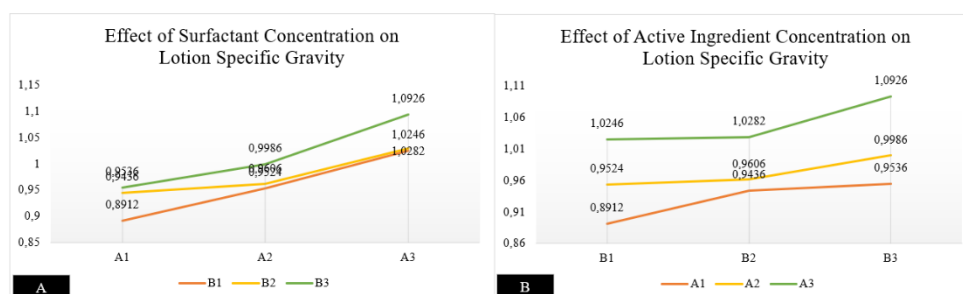


Figure 5. Effect of Surfactant (A) and Active Ingredient (B) Concentration on Sunscreen Lotion Type Weight

Based on Figure 5A, it can be seen that an increase in the proportion of cetyl alcohol consistently increases the weight of the lotion type on all variations of the active ingredient. This increase appears linear from A1 (± 0.89 – 0.95) to A3 (± 1.02 – 1.09), with the highest value in combination A3B3 (1.09). The relatively parallel line pattern between B1, B2, and B3 shows that the effect of surfactants is dominant and consistent on specific weights. Mechanistically, the increase of cetyl alcohol as a co-emulsifier and thickening agent is able to strengthen the structure of the emulsion and increase the viscosity, so that the density of the system increases. This is in line with Aditha *et al.* (2024), which states that the increase in emulsifier components can strengthen the interaction between phases and increase the density of the preparation.

Meanwhile, in Figure 5B, it can be seen that the increase in the concentration of active ingredients also increases the specific weight, but with a slower gradient than the surfactant factor. At each surfactant ratio, the increase in type weight takes place relatively uniformly, which indicates an independent contribution of the active ingredient in the absence of strong interactions. The role of TiO_2 as a material with high density is a major factor in the increase in density, whereas EEOPL contributes to the system without significantly changing the pattern. This is in line with the results of ANOVA which showed that surfactants and active ingredients had a significant effect separately, but the interaction was not significant. Thus, the weight of the lotion type is more influenced by the structure of the emulsion formed by the surfactant, while the active ingredient acts as a supporting factor in increasing the density of the preparation.

Organoleptic Tests

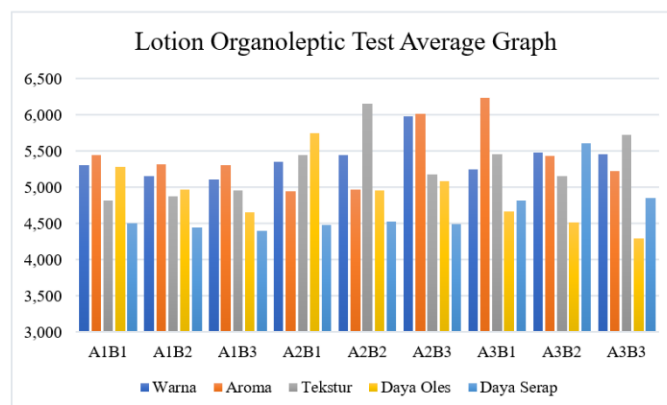


Figure 6. Average Results of Organoleptic Test of Sunscreen Lotion

Based on the average graph of organoleptic tests, all treatments were in the neutral to somewhat favorable range (± 4.5 – 6.0). Overall, combinations with balanced to dominant surfactants of cetyl alcohol, particularly A2B2, A2B3, A3B1, and A3B2, tend to give higher values on several parameters such as color, aroma, and texture. Meanwhile, the combination of A1B1, A1B2, and A1B3 generally showed lower and relatively uniform values, indicating that Tween 80's dominance was less able to produce optimal sensory characters. However, increasing the concentration of active ingredients does not necessarily increase the level of preference. This can be seen in the application power parameters, where the combination of A3B3 shows the lowest value, and a decrease is also seen in A1B3 and A3B2 compared to the previous combination. In contrast, the highest application value is found in A2B1, which indicates that a lower concentration of active ingredients with a balanced surfactant ratio provides the best ease of application. In general, these results confirm that a balanced combination of formulations (mainly A2 and partial A3) is more determinative of organoleptic acceptance than simply an increase in the concentration of active ingredients.

Homogeneity Test

Table 2. Homogeneity Test Results of Sunscreen Lotion Preparations

Treatment	Detestation	
	Block I	Block II
A1B1	Homogeneous	Homogeneous
A1B2	Homogeneous	Homogeneous
A1B3	Homogeneous	Homogeneous
A2B1	Homogeneous	Homogeneous
A2B2	Homogeneous	Homogeneous
A2B3	Homogeneous	Homogeneous
A3B1	Homogeneous	Homogeneous
A3B2	Homogeneous	Homogeneous
A3B3	Homogeneous	Homogeneous

Based on Table 2, all treatment combinations (A1B1 to A3B3) in both tests showed homogeneous results, which were characterized by the absence of coarse grains, phase separation, and unmixing of components in the lotion preparation. These results indicate that the emulsion system formed is able to disperse the active ingredients, both TiO_2 and palm leaf ethanol extract, evenly within the lotion base. Good homogeneity reflects that the combination of Tween 80 and cetyl alcohol in all ratios used has been effective as a surfactant and co-emulsifier in maintaining dispersion stability. Formulationally, this success indicates that a total surfactant concentration of 5% b/b is sufficient to produce a stable and uniform emulsion system across all variations of the active ingredient. Consistent homogeneity throughout the treatment is also an early indicator that the preparation has good physical quality, so it can support an even distribution of the active

ingredient during application and potentially increase the effectiveness and comfort of using the product.

CONCLUSION

Based on the results of the study, it can be concluded that the combination of Tween 80 surfactant and cetyl alcohol significantly affected the physical characteristics of the sunscreen lotion, particularly viscosity, pH, specific gravity, and SPF value, while the variation of active ingredients consisting of TiO₂ and ethanol extract of oil palm leaves significantly affected SPF value and antioxidant activity but did not significantly affect viscosity and pH. An increase in the proportion of cetyl alcohol tended to improve viscosity, pH, specific gravity, and SPF effectiveness, whereas increasing the concentration of active ingredients contributed to higher SPF values and antioxidant activity. The highest SPF value of 4.30 and antioxidant activity of 95.51% were obtained in treatment A3B2, while the lowest antioxidant activity value of 87.97% was observed in treatment A1B1. From the organoleptic evaluation, formulation A2B3 was the most preferred by the panelists. Overall, sunscreen lotion formulations based on Palm Kernel Oil (PKO) and Virgin Coconut Oil (VCO) with the addition of ethanol extract of oil palm leaves demonstrated good physical stability and high antioxidant activity, indicating their potential to be developed as innovative and sustainable natural sunscreen preparations. The practical implication of this study is that oil palm leaf waste can be utilized as a value-added natural antioxidant source for cosmetic and sunscreen products, supporting environmentally friendly and sustainable product development. However, because the SPF value obtained was still categorized as low protection, further studies are recommended to optimize the formulation by adding other UV-filter agents such as zinc oxide (ZnO) to enhance SPF effectiveness, as well as conducting long-term stability testing, irritation testing, microbial evaluation, and in vivo SPF analysis to ensure product safety, stability, and effectiveness.

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