International Journal of Multidisciplinary Sciences and Arts
E-ISSN :2962-1658
Volume 5, Number 3, July 2026
https://doi.org/10.47709/ijmdsa.v5i3.9349

Effect of *Sonneratia alba* Leaf Extract on Antioxidant Activity and Moisturizer Gel Properties

Rahmiati Molamahu[1], Faiza A. Dali[2*], Sri Rahayu Kalaka[3]
[1,2,3]State University of Gorontalo, Gorontalo, Indonesia
[*]faizadali@ung.ac.id

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***Corresponding Author**

Article History:
Submitted: 21-07-2026
Accepted: 28-07-2026
Published: 31-07-2026

Keywords:
Antioxidant activity; carbopol; moisturizer gel; physical properties; *Sonneratia alba.*

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ABSTRACT

The skin functions as the primary barrier against environmental stressors, where ultraviolet radiation and pollutants induce oxidative stress and accelerate premature aging. Although *Sonneratia alba* leaves possess considerable antioxidant potential, information regarding their application in moisturizer gel formulations remains limited. This study evaluated the effect of different concentrations of *S. alba* leaf extract on the antioxidant activity and physical properties of a moisturizer gel. A completely randomized design was employed using extract concentrations of 0% (control), 10%, 15%, and 20% (w/w) incorporated into a Carbopol-based gel formulation. Antioxidant activity was determined using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, while viscosity and spreadability were evaluated as physical quality parameters. The results showed that antioxidant activity ranged from 72.41% to 73.11% inhibition, with no significant differences among extract concentrations ($p > 0.05$), indicating that antioxidant capacity was maintained after gel formulation. In contrast, increasing extract concentration significantly reduced viscosity ($p < 0.05$) and significantly affected horizontal spreadability, whereas vertical spreadability remained unchanged. These findings suggest that *S. alba* extract modified the rheological characteristics of the gel without compromising its antioxidant activity. The formulation containing 20% extract exhibited the highest mean antioxidant activity while maintaining acceptable physical characteristics, indicating its potential as a natural active ingredient for antioxidant moisturizer gel formulations.

INTRODUCTION

Human skin is continuously exposed to ultraviolet radiation, environmental pollutants, and other external stressors that promote excessive generation of reactive oxygen species (ROS). Although physiological levels of ROS are involved in normal cellular signaling and skin homeostasis, excessive ROS production exceeding the endogenous antioxidant defense system induces oxidative stress, leading to lipid peroxidation, protein oxidation, DNA damage, and accelerated skin aging (Jaffri, 2023; Jomova et al., 2023). Therefore, topical antioxidants have attracted increasing attention because they can scavenge free radicals and reduce oxidative damage while supporting the maintenance of healthy skin.

Moisturizers are among the most widely used topical formulations because they improve skin hydration by reducing transepidermal water loss and enhancing the integrity of the stratum corneum. Depending on their composition, moisturizers exert their effects through humectant, emollient, and occlusive mechanisms, thereby improving skin softness and maintaining epidermal water balance Moisturizers are among the most widely used topical formulations because they improve skin hydration by reducing transepidermal water loss (TEWL) and enhancing the integrity of the stratum corneum. Depending on their composition, moisturizers exert their effects through humectant, emollient, and occlusive mechanisms, thereby improving skin softness and maintaining epidermal water balance (Mawazi et al., 2022; Rajkumar et al., 2023). Among topical dosage forms, gels are widely preferred because they provide a lightweight, non-greasy texture, are easily washed from the skin, exhibit good spreadability, and achieve satisfactory physical stability when formulated with appropriate gelling agents such as Carbopol or HPMC (Aziza et al., 2025; Wahidah et al., 2024).

One promising botanical resource is the mangrove species *S. alba*, which is widely distributed in Indonesian coastal ecosystems. Although the fruits and wood of this species have been utilized for various purposes, its leaves remain relatively underexploited despite being rich in bioactive phytochemicals. Previous studies have demonstrated that *S. alba* leaves contain phenolic compounds, flavonoids, tannins, and saponins that exhibit remarkable antioxidant properties (Binuni et al., 2020). Ethanol extracts of *Sonneratia* leaves have been reported to possess strong free radical scavenging activity, with IC_{50} values ranging from approximately 28 to 68 ppm in DPPH and ABTS assays (Raharjo et al., 2024). These phenolic constituents are highly compatible with hydrophilic gel systems, suggesting their potential application as natural antioxidant ingredients in topical formulations (Rajkumar et al., 2023).

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Despite the documented antioxidant potential of *S. alba* leaf extracts, previous investigations have primarily focused on physical characterization and antioxidant activity of the extracts themselves. Limited information is available regarding the influence of different extract concentrations on the physicochemical characteristics of moisturizer gel formulations, particularly antioxidant activity after formulation, viscosity, and spreadability. These properties are essential quality attributes because they determine formulation stability, ease of application, and consumer acceptability. Therefore, this study aimed to evaluate the effect of different concentrations of *S. alba* leaf extract on the antioxidant activity and physical properties of moisturizer gels.

LITERATURE REVIEW

Sonneratia alba Leaf Extract as a Natural Antioxidant

Sonneratia alba is a mangrove species widely distributed in tropical coastal regions and recognized as a promising source of natural antioxidants. Ethanol extracts of *S. alba* leaves contain phenolic compounds, flavonoids, tannins, and saponins, which contribute to strong free radical scavenging activity (Binuni et al., 2020). Previous studies reported IC_{50} values ranging from approximately 28 to 68 ppm, indicating high antioxidant potential (Raharjo et al., 2024). These bioactive compounds make *S. alba* leaves a potential active ingredient for topical cosmetic formulations intended to protect the skin from oxidative stress.

Moisturizer Gel and Physicochemical Characteristics

Moisturizers are formulated to maintain skin hydration by enhancing the barrier function of the stratum corneum, increasing stratum corneum water content, and reducing transepidermal water loss (Mawazi et al., 2022; Rajkumar et al., 2023). Gel formulations are widely preferred because they provide a light, non-greasy texture, spread easily over the skin, and are readily removed with water (Wahidah et al., 2024). Carbopol is one of the most widely used gelling agents because it produces transparent gels with desirable viscosity and physical stability after neutralization (Aziza et al., 2025). However, incorporation of plant extracts may interfere with the polymeric gel network, thereby altering rheological behavior and other physical properties, including viscosity and spreadability.

Antioxidant Activity, Viscosity, and Spreadability

Antioxidant activity is essential for protecting the skin against oxidative stress and is commonly evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, a rapid and reliable method for estimating the free radical scavenging capacity of natural compounds (Jaffri, 2023; Dali et al., 2025). Viscosity is a key rheological parameter that governs the consistency, physical stability, and application performance of semisolid formulations, whereas spreadability determines the ease of application and uniform distribution of the product over the skin surface. These properties are closely interrelated because a reduction in viscosity generally facilitates greater spreadability, thereby enhancing topical application and consumer acceptability (Aziza et al., 2025; Singh et al., 2026).

METHOD

Experimental Design

This study employed a Completely Randomized Design (CRD) consisting of four treatments with two replications. Moisturizer gels were formulated by incorporating *Sonneratia alba* leaf extract at concentrations of 0% (control), 10%, 15%, and 20% (w/w). The formulated gels were subsequently evaluated for antioxidant activity, viscosity, and spreadability.

Preparation of *Sonneratia alba* Leaf Extract

Fresh *Sonneratia alba* leaves were collected from South Pinolosian Village, Pinolosian District, South Bolaang Mongondow Regency, North Sulawesi, Indonesia. The leaves were washed thoroughly with running water, oven-dried at 60°C, and ground into fine powder. The extraction procedure was adapted from Shofiah (2024) with modifications. Briefly, 300 g of powdered leaves were macerated with 900 mL of 96% ethanol (1:3, w/v) for 72 h at room temperature with occasional stirring. The extract was filtered and concentrated using a rotary evaporator at 40–50°C under reduced pressure, followed by evaporation in a water bath at 60°C to obtain a viscous crude extract.

Formulation of Moisturizer Gel

Moisturizer gels were prepared according to the formulation adapted from Shofiah (2024) with slight modifications (Table 1).

Table 1. Formulation of moisturizer gels containing different concentrations of *S. alba* leaf extract

Ingredient	Unit	0% (Control)	10%	15%	20%
***S. alba* leaf extract**	mL	–	13.2	21.0	29.8
Carbopol	g	2.0	2.0	2.0	2.0
Triethanolamine (TEA)	mL	2.0	2.0	2.0	2.0
Glycerin	mL	10.0	10.0	10.0	10.0

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Propylene glycol	mL	5.0	5.0	5.0	5.0
Methyl paraben	g	0.2	0.2	0.2	0.2
Distilled water	mL	To 100	To 100	To 100	To 100

Carbopol was dispersed in distilled water at approximately 70°C to form the gel base and neutralized with triethanolamine (TEA). Glycerin was incorporated as a humectant, while methyl paraben was dissolved in propylene glycol before being added to the gel base. *Sonneratia alba* leaf extract was subsequently incorporated according to each treatment concentration (0%, 10%, 15%, and 20%, w/w), and the mixture was stirred continuously until a homogeneous gel was obtained.

Antioxidant Activity Analysis by the DPPH Radical Scavenging Assay

The antioxidant activity was determined using the DPPH radical scavenging assay with slight modifications from Dali et al. (2025). Briefly, 2 mL of gel sample was mixed with 2 mL of 0.1 mM DPPH solution, incubated in the dark at room temperature for 30 min, and absorbance was measured at 517 nm using a UV–Vis spectrophotometer. Radical scavenging activity (%) was calculated as follows:

$$Inhibition\ (\%) = \frac{Absorbance\ of\ the\ control - Absorbance\ of\ the\ sample}{Absorbance\ of\ the\ control} X\ 100\%$$

Viscosity Measurement

Viscosity was measured using a Brookfield viscometer with spindle No. 64 at 62 rpm. The spindle was fully immersed in the gel sample, and the viscosity was recorded in centipoise (cP).

Spreadability Test

Spreadability was determined following the method of Putri and Anindhita (2022) with slight modifications. Approximately 0.5 g of the gel sample was placed between two glass plates, followed by the application of a standardized load. After a fixed standing period, the vertical and horizontal diameters of the spread gel were measured using a digital caliper and recorded in millimeters (mm). Each formulation was analyzed in duplicate, and the average values were used for statistical analysis.

Statistical Analysis

All experiments were conducted in duplicate, and the results are expressed as mean ± standard deviation (SD). Statistical analysis was performed using one-way analysis of variance (ANOVA) to determine the effect of *S. alba* leaf extract concentration on antioxidant activity, viscosity, and spreadability. Significant differences among treatments were further analyzed using Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$.

RESULT

Antioxidant Activity

The antioxidant activity of moisturizer gels containing different concentrations of *S. alba* leaf extract was evaluated using the DPPH radical scavenging assay. The results are presented in Table 2.

Table 2. DPPH radical scavenging activity of moisturizer gels containing different concentrations of *S. alba* leaf extract

Extract concentration (%)	DPPH radical scavenging activity (% inhibition)
0 (Control)	–
10	72.41 ± 2.66[a]
15	72.87 ± 2.96[a]
20	73.11 ± 2.89[a]

Values are presented as mean ± standard deviation. Means followed by the same superscript letter within the same column are not significantly different according to DMRT ($p > 0.05$)

The DPPH radical scavenging activity ranged from 72.41% to 73.11%. Statistical analysis showed that increasing the concentration of *S. alba* leaf extract from 10% to 20% did not significantly affect the antioxidant activity of the formulated gels ($p > 0.05$).

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Viscosity

The viscosity values of moisturizer gels formulated with different concentrations of *S. alba* leaf extract are summarized in Table 3.

Table 3. Viscosity of moisturizer gels containing different concentrations of *S. alba* leaf extract

Extract concentration (%)	Viscosity (cP)
0 (Control)	44.00 ± 1.41d
10	29.75 ± 0.35c
15	**16.75 ± 0.35b**
20	10.25 ± 1.06a

Values are presented as mean ± standard deviation. Means followed by different superscript letters within the same column indicate significant differences according to DMRT ($p < 0.05$)

Viscosity values ranged from 10.25 to 44.00 cP. The control formulation exhibited the highest viscosity, whereas the formulation containing 20% extract exhibited the lowest viscosity. Significant differences were observed among all treatments ($p < 0.05$).

Spreadability

The spreadability of the formulated moisturizer gels was determined by measuring both vertical and horizontal spreading diameters. The results are presented in Table 4.

Table 4. Spreadability of moisturizer gels containing different concentrations of *S. alba* leaf extract

Extract concentration (%)	Vertical spread (mm)	Horizontal spread (mm)
0 (Control)	43.78 ± 5.31[a]	47.16 ± 0.53c
10	35.21 ± 2.19b	37.14 ± 1.41c
15	41.90 ± 3.23a	38.03 ± 1.13ab
20	44.48 ± 1.29a	40.83 ± 1.29b

Values are presented as mean ± standard deviation. Means followed by different superscript letters within the same column indicate significant differences according to DMRT ($p < 0.05$)

The vertical spreadability ranged from 35.21 to 44.48 mm, whereas the horizontal spreadability ranged from 37.14 to 47.16 mm. Significant differences among treatments were observed for both spreadability measurements according to DMRT ($p < 0.05$).

DISCUSSION

Antioxidant Activity

The antioxidant activity of *Sonneratia alba* leaf extract incorporated into the moisturizer gel was evaluated using the DPPH radical scavenging assay. The formulations exhibited inhibition values ranging from 72.41 ± 2.66% to 73.11 ± 2.89%, and no significant differences were detected among extract concentrations ($p > 0.05$). Although the antioxidant activity increased slightly with increasing extract concentration, the magnitude of improvement was insufficient to produce statistically distinguishable responses.

The absence of significant differences indicates that the incorporation of 10% *S. alba* extract was already sufficient to provide a high level of antioxidant compounds capable of scavenging DPPH radicals under the experimental conditions. Since the gel base composition remained identical across formulations, increasing the extract concentration beyond this level likely contributed only a limited increase in available antioxidant molecules, resulting in a plateau-like response. Similar phenomena have been reported in antioxidant assays when radical scavenging capacity approaches saturation, causing further increases in antioxidant concentration to produce only marginal improvements in inhibition.

The strong antioxidant activity observed in all formulations is consistent with the phytochemical composition of *S. alba* leaves, which contains phenolic compounds, flavonoids, tannins, and other secondary metabolites capable of donating hydrogen atoms or electrons to neutralize free radicals. These compounds interrupt oxidative chain reactions and mitigate oxidative stress induced by ultraviolet radiation, environmental pollutants, and other environmental stressors associated with premature skin aging (Jaffri, 2023; Jomova et al., 2023).

The present findings agree with those of Binuni et al. (2020), who reported increasing DPPH radical scavenging activity with increasing concentrations of *S. alba* leaf extract, reaching 74.67% inhibition at the highest concentration evaluated. The inhibition values obtained in the present study (72.41–73.11%) were comparable to those reported by Binuni et al., indicating that incorporation of the extract into a Carbopol-based moisturizer gel preserved its antioxidant capacity. Similar observations have also been reported for moisturizer gels prepared from *Artocarpus altilis* leaf extract, in which increasing extract concentration enhanced antioxidant activity despite differences in the magnitude of inhibition (Shofiah, 2024). Variations among studies are expected because antioxidant performance is influenced by plant species, phytochemical composition, extraction procedures, formulation composition, and assay conditions.

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E-ISSN :2962-1658
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Viscosity

Viscosity is a critical quality parameter of semisolid topical formulations because it affects physical stability, consistency, and ease of application. In the present study, increasing the concentration of *S. alba* leaf extract significantly reduced gel viscosity ($p < 0.05$). The control formulation exhibited the highest viscosity (44,000 ± 1,410 cP), whereas the formulation containing 20% extract showed the lowest viscosity (10,250 ± 1,060 cP). Duncan's multiple range test further confirmed that each formulation differed significantly, indicating that increasing extract concentration consistently altered the rheological characteristics of the moisturizer gel.

The decrease in viscosity is most likely attributable to interactions between soluble constituents of the *S. alba* leaf extract and the Carbopol gel matrix. Following neutralization with triethanolamine, Carbopol develops a three-dimensional polymeric network responsible for the viscosity, consistency, and physical stability of topical gel formulations (Aziza et al., 2025). Incorporation of increasing concentrations of the extract introduces phenolic compounds, flavonoids, tannins, and other water-soluble constituents that may interfere with polymer chain interactions, thereby reducing polymer entanglement and weakening the gel network. Furthermore, the additional liquid fraction contributed by the extract increases the aqueous phase of the formulation, resulting in lower resistance to flow and consequently reduced viscosity. Similar rheological responses have been reported for Carbopol-based gels containing plant-derived active ingredients, in which interactions between bioactive compounds and the polymer matrix significantly influence gel viscosity and overall physical performance (Wahidah et al., 2024; Singh et al., 2026).

The present findings are also consistent with those reported by Ambarita et al. (2025), who demonstrated that incorporation of *Syzygium polyanthum* leaf extract into topical lotion formulations influenced viscosity while maintaining acceptable physical quality for cosmetic application. Appropriate viscosity is essential because it contributes to formulation stability during storage while ensuring that the product can be applied easily and uniformly to the skin.

Despite the significant reduction in viscosity, all formulations remained within the generally accepted viscosity range for topical semisolid preparations (2,000–50,000 cP). Therefore, increasing the concentration of *S. alba* leaf extract improved the incorporation of natural bioactive compounds without compromising the physical suitability of the moisturizer gel.

Spreadability

Spreadability is an important quality attribute of topical gels because it influences ease of application and determines the extent to which the formulation can be uniformly distributed across the skin surface. In the present study, extract concentration significantly affected horizontal spreadability but had no significant effect on vertical spreadability. These findings indicate that increasing the concentration of *S. alba* leaf extract modified the rheological behavior of the gel without producing uniform changes in spreading characteristics in every direction.

The observed differences in spreadability are closely associated with the rheological changes induced by increasing extract concentration. As gel viscosity decreased, less force was required to deform the gel, facilitating greater horizontal spreading during testing. However, the absence of significant differences in vertical spreadability indicates that spreading behavior is governed not only by viscosity but also by the overall formulation composition and the physical characteristics of the gel matrix. Consequently, spreadability reflects the combined influence of formulation composition, polymer characteristics, and rheological behavior rather than viscosity alone (Agustiani et al., 2022; Aziza et al., 2025). This explanation is consistent with the present findings, in which horizontal spreadability increased as viscosity decreased, whereas vertical spreadability remained statistically unchanged, indicating that extract incorporation modified gel rheology without uniformly altering spreading behavior.

An inverse relationship between viscosity and spreadability has been widely described for semisolid topical formulations, in which lower viscosity generally promotes greater spreading during application (Putri & Anindhita, 2022; Singh et al., 2026). The present findings generally support this relationship, although the response was not completely linear across all formulations. This indicates that the physicochemical interactions occurring within the gel matrix also contributed to the observed spreading behavior.

Comparable observations were reported by Wahidah et al. (2024), who concluded that the rheological properties of topical gels are strongly influenced by the type of gelling polymer and its interactions with incorporated active ingredients. Likewise, Alfian et al. (2022) demonstrated that spreadability is determined not only by viscosity but also by the overall formulation composition, including the concentration of the active extract and the gelling agent. These findings support the interpretation that modification of gel composition affects spreadability through multiple physicochemical mechanisms.

Although all formulations could be applied without difficulty, the measured spreadability values (3.52–4.72 cm) remained below the generally recommended range of 5–7 cm for topical gel preparations (Putri & Anindhita, 2022). Therefore, further optimization of the gel base, particularly the concentration of Carbopol or other formulation components, may improve spreadability while maintaining the desirable antioxidant activity and acceptable viscosity achieved in the present study.

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CONCLUSION

The incorporation of *Sonneratia alba* leaf extract into moisturizer gel successfully produced a topical formulation with high antioxidant activity and acceptable physical characteristics. Increasing the extract concentration from 10% to 20% did not significantly affect DPPH radical scavenging activity, indicating that antioxidant activity was maintained across all formulations. In contrast, extract concentration significantly reduced gel viscosity, demonstrating that the extract influenced the Carbopol gel network while still maintaining viscosity within the acceptable range for topical gel products. Extract concentration also significantly affected horizontal spreadability but had no significant effect on vertical spreadability, suggesting that spreading behavior was influenced by both rheological properties and gel structure. Overall, the formulation containing 20% *S. alba* leaf extract exhibited the highest antioxidant activity with acceptable physical characteristics, indicating its potential as a natural active ingredient for antioxidant moisturizer gel formulations. Future studies should optimize the gel base composition to improve spreadability while maintaining formulation stability and investigate additional quality attributes, including pH, storage stability, skin compatibility, and *in vivo* efficacy to support the development of *S. alba*-based cosmetic products.

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