Pharmacy Reports

https://doi.org/10.51511/pr.110

ORIGINAL ARTICLE

Open Access

Photoprotective efficacy and physicochemical stability of sunscreen gel containing *Averrhoa bilimbi* L. leaf extract

Rega Gustiya Wittami, Annisa Maulidia Rahayyu*, Untia Kartika Sari Ramadhani

Department of Pharmacy, Faculty of Science, Institut Teknologi Sumatera

*Corresponding author: Jl Terusan Ryacudu, Way Hui, Jati Agung, South Lampung 35365. Email: annisa.rahayyu@fa.itera.ac.id

Abstract: Chronic UV-B exposure causes significant skin damage, necessitating effective photoprotective strategies. This study developed and evaluated sunscreen gel formulations containing ethanolic extracts of *Averrhoa bilimbi* leaves at varying concentrations. Extraction was performed using ultrasonic-assisted extraction (UAE), while sun protection factor (SPF) determination employed the Mansur spectrophotometric method. Four gel formulations were prepared: F0 (0%, control), F1 (0.2%), F2 (1%), and F3 (5% extract). Physicochemical characterization revealed that all formulations exhibited acceptable organoleptic properties, homogeneity, pH (4.5 to 7.0), viscosity (2,000 to 50,000 cps), spreadability (5 to 7 cm), and adhesiveness (>1 second). Accelerated stability testing demonstrated stable pH, viscosity, spreadability, and SPF values, although adhesiveness showed statistical variation while remaining within acceptable limits. SPF analysis revealed concentration-dependent photoprotective efficacy: F1 achieved maximum protection, while F2 and F3 demonstrated ultraprotection, with F3 exhibiting the highest SPF value of 36.9. These findings confirm that increased *A. bilimbi* extract concentration correlates with enhanced photoprotective activity, establishing the potential of this natural ingredient for sunscreen applications.

Keywords: *Averrhoa bilimbi*, natural sunscreen, sun protection factor, gel formulation, photoprotective activity

Introduction

Indonesia's geographical location along the equatorial belt results in prolonged exposure to solar radiation throughout the year, placing the population at elevated risk for UV-induced skin damage. Among the components of solar radiation, UV-B (280 to 320 nm) is recognized as the primary causative agent of skin cancer due to its direct absorption by cellular DNA, leading to mutagenic molecular modifications. UV-B radiation poses a more severe carcinogenic threat compared to UV-A (320 to 400 nm), which predominantly contributes to photoaging through indirect generation of reactive oxygen species via photosensitization processes [1].

The incidence of skin cancer in Indonesia has demonstrated a concerning upward trend over the past decade. Epidemiological data indicate approximately 2 to 3 million cases of non-melanoma skin cancer and 132,000 cases of melanoma annually [2]. Skin cancer ranks third among cancers affecting Indonesian women, following cervical and breast cancers, with annual incidence rates ranging from 5.9% to 7.8% [3]. These statistics underscore the critical need for effective photoprotective strategies in tropical populations.

Sunscreen products represent a primary preventive measure against UV-induced skin damage. These topical cosmetic formulations function through three distinct mechanisms: absorption, scattering, or reflection of UV radiation [4]. The photoprotective efficacy of sunscreen products is quantified using the Sun Protection Factor (SPF), which measures the degree of protection against UV-B-induced erythema. Sunscreen formulations incorporating adequate SPF values provide a practical and accessible approach to reducing the risk of acute sunburn and long-term photodamage, including carcinogenesis.

Recent research has increasingly focused on natural plant-derived photoprotective agents as alternatives or supplements to synthetic UV filters. This trend is driven by consumer preference for natural products, concerns regarding the safety profile of certain synthetic UV filters, and potential environmental impacts of conventional sunscreen ingredients. Plant extracts rich in polyphenolic compounds, particularly flavonoids and phenolic acids, have demonstrated promising UV-absorbing and antioxidant properties, making them suitable candidates for natural sunscreen development.

Averrhoa bilimbi L., commonly known as *bilimbi* or *belimbing wuluh*, is a tropical fruit tree belonging to the family Oxalidaceae. The leaves of this plant have been utilized in various topical formulations, including bath soaps, antioxidant creams, and peel-off masks, demonstrating its versatility in cosmetic applications [5]. Phytochemical investigations have revealed that *A. bilimbi* leaves contain substantial quantities of bioactive secondary metabolites, including flavonoids, phenolic compounds, and tannins, which possess both antioxidant and potential photoprotective properties. These compounds feature conjugated aromatic systems capable of absorbing UV radiation, suggesting their suitability as natural sunscreen agents.

Despite the documented bioactivity of *A. bilimbi* leaf extracts and their incorporation into various cosmetic formulations, no previous studies have specifically investigated their potential as active ingredients in sunscreen gel formulations. Gel-based delivery systems offer several advantages over other topical dosage forms, including superior skin absorption, non-greasy texture, easy application, and favorable aesthetic properties [6]. The semi-solid nature of gels provides both the spreadability of lotions and the substantivity of creams, making them particularly suitable for sunscreen applications where uniform skin coverage is essential.

Given the established presence of UV-absorbing phytochemicals in *A. bilimbi* leaves and the absence of prior research on gel-based sunscreen formulations from this plant material, the present study was designed to address this knowledge gap. The primary objectives of this investigation were: (1) to formulate sunscreen gel preparations incorporating varying concentrations of *A. bilimbi* ethanolic leaf extract, (2) to evaluate the physicochemical properties and stability of the developed formulations, and (3) to determine their photoprotective efficacy through SPF value assessment. The findings of this study are expected to contribute to the development of effective, plant-based sunscreen products and expand the cosmetic applications of *A. bilimbi* leaf extracts.

This research employed ultrasonic-assisted extraction (UAE) to obtain ethanolic extracts of *A. bilimbi* leaves, which were subsequently incorporated into gel formulations at concentrations of 0.2%, 1%, and 5%, alongside a control formulation without extract. The physicochemical characterization encompassed organoleptic evaluation, homogeneity, pH, viscosity, spreadability, and adhesiveness testing. Accelerated stability assessment was conducted using cycling test methodology, and photoprotective efficacy was determined using the spectrophotometric Mansur method for SPF calculation. Through this approach, the study aimed to establish the feasibility and optimize the composition of natural sunscreen gels derived from *A. bilimbi* leaf extracts.

Methods

Plant material collection and authentication

Fresh mature leaves of *Averrhoa bilimbi* L. were collected from Jalan Bangau Perum BW, Way Huwi Village, Jati Agung District, South Lampung Regency, Lampung Province, Indonesia. Plant authentication was performed at the Botany Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, University of Lampung, to confirm the botanical identity and prevent contamination with other species. The specimen was identified as *Averrhoa bilimbi* L. (family Oxalidaceae).

Preparation of dried leaf powder

The fresh leaves (1.53 kg) were subjected to wet sorting, washed thoroughly with tap water, and dried under direct sunlight until completely dry, indicated by a crisp texture when crushed. After dry sorting, the dried leaves were ground using a blender and sieved to obtain a fine powder (simplicia). Moisture content of the powder was determined using a moisture analyzer and maintained below 10% as required by standard herbal processing protocols. The simplicia yield was calculated using the formula: (weight of dried simplicia / weight of fresh leaves) × 100%.

Extraction procedure

Ethanolic extraction was performed using the ultrasonic assisted extraction method following the procedure described by Andriani et al. (2019) [7]. Briefly, 50 g of dried leaf powder was weighed using a digital balance, transferred into a glass beaker, and dissolved in 500 mL of 70% ethanol. The mixture was subjected to ultrasonic extraction at 40°C for 20 minutes. The resulting solution was filtered, and the filtrate was concentrated using a rotary evaporator at 40°C and 100 rpm. The concentrated extract was weighed, and the extraction yield was calculated as: (weight of extract / weight of dried powder) × 100%.

Table 1. Composition of sunscreen gel formulations

Ingredient	Function	Formula (% w/v)			
		F0	F1	F2	F3
A. bilimbi ethanolic extract	Active ingredient	0	0.2	1	5
Carbopol 940	Gelling agent	1	1	1	1
Glycerin	Humectant	10	10	10	10
Methylparaben	Preservative	0.2	0.2	0.2	0.2
TEA	Neutralizing agent	1	1	1	1
Distilled water	Solvent	up to 100	up to 100	up to 100	up to 100

Phytochemical screening

Preliminary phytochemical screening was conducted to identify the presence of major secondary metabolites in the ethanolic extract using standard qualitative methods [8].

Phenolic compounds. Two milliliters of extract was mixed with 10 drops of 1% $FeCl_3$ solution. Formation of a green, purple, blue, or dark black precipitate indicated the presence of phenolic compounds [8].

Flavonoids. Two milliliters of extract was mixed with 100 mL of boiling water (aqua fervida), boiled for 5 minutes, and filtered. Five milliliters of the filtrate was collected, followed by addition of magnesium powder and 1 mL of concentrated HCl, then shaken vigorously. Development of red, yellow, or orange coloration indicated the presence of flavonoids [8].

Tannins. One to two milliliters of ethanolic extract was treated with 2 to 3 drops of 10% $FeCl_3$ solution. A color change to greenish or black indicated the presence of tannins [8].

Gel formulation and preparation

Four gel formulations were prepared with varying concentrations of *A. bilimbi* leaf extract: F0 (0%, control), F1 (0.2%), F2 (1%), and F3 (5%). The composition of each formulation is presented in Table 1. The gel base consisted of Carbopol 940 as the gelling agent, glycerin as a humectant, methylparaben as a preservative, triethanolamine as a neutralizing agent, and distilled water as the solvent.

The gel was prepared according to the following procedure adapted from Buang et al. (2021): Carbopol 940 was dispersed in hot distilled water at a ratio of 1:20 (w/v) and allowed to swell [9]. In a separate beaker, methylparaben was dissolved in hot distilled water. The swollen Carbopol was stirred with a glass rod, and triethanolamine was added dropwise while stirring continuously until a clear gel base was formed. The *A. bilimbi* extract was dispersed in glycerin, mixed until homogeneous, and incorporated into the gel base. The methylparaben solution was then added and mixed thoroughly until a uniform gel was obtained. The final product was transferred into appropriate containers.

Physicochemical characterization

Organoleptic evaluation. The color, odor, and texture of each gel formulation were examined visually and recorded. An acceptable gel should exhibit color and aroma consistent with the active ingredient and possess a texture that is neither too fluid nor too viscous [10].

Homogeneity test. A small amount of gel was spread between two glass slides and observed under transmitted light for the presence of undissolved particles. Acceptable gels should exhibit uniform consistency without visible particulate matter [11].

pH measurement. A pH meter was calibrated using acetate buffer (pH 4.0) and phosphate buffer (pH 7.0). One gram of gel was diluted in 10 mL of distilled water, and the pH was measured. The acceptable pH range for topical gels is 4.5 to 7.0, corresponding to the physiological pH of human skin [12].

Viscosity determination. Fifty grams of gel was placed in a container, and spindle No. 11 was immersed into the sample. Viscosity was measured using a rotational viscometer at 40 rpm. The acceptable viscosity range for topical gels is 2,000 to 50,000 cps [10].

Spreadability test. A 0.5 g sample of gel was placed on a 7 cm diameter glass plate, covered with another glass plate, and subjected to a 50 g load for one minute. The diameter of the spread gel was measured.

An acceptable spreadability diameter ranges from 5 to 7 cm [10].

Adhesiveness test. A 0.5 g sample of gel was placed between two glass slides, pressed with a 50 g load, and allowed to stand for three minutes. The time required to separate the two glass slides was recorded. Acceptable adhesiveness should exceed 1 second [10].

Accelerated stability testing

Stability assessment was conducted using a cycling test method over 12 days. Gel samples were stored at 4°C for 24 hours, followed by 40°C for 24 hours, constituting one cycle of 2 days. This procedure was repeated for six complete cycles. Physicochemical parameters (pH, viscosity, spreadability, and adhesiveness) were evaluated before and after the stability test [5].

SPF value determination

Test solutions with a concentration of 20,000 µg/mL were prepared from the extract and each gel formulation. Samples were transferred into a 5 mL volumetric flask and diluted to volume with 70% ethanol [9].

SPF values were determined using UV-Vis spectrophotometry according to the Mansur method. Absorbance was recorded at 5 nm intervals from 290 to 320 nm in triplicate. The mean absorbance at each wavelength was multiplied by the corresponding erythema effect (EE) × solar intensity (I) values, and the sum was multiplied by a correction factor (CF) of 10 to obtain the SPF value (Table 2) [9]. The SPF was calculated using the following equation:

$$\text{SPF spectrophotometric} = \text{CF} \times \sum_{290}^{320} \text{EE}(\lambda) \times \text{I}(\lambda) \times \text{Abs}(\lambda)$$

where EE represents the erythemal effect spectrum, I represents the solar intensity spectrum, Abs represents the absorbance of the sunscreen product, and CF is the correction factor with a value of 10.

Table 2. Normalized product function used for SPF calculation

Wavelength (λ, nm)	EE × I
290	0.0150
295	0.0817
300	0.2874
305	0.3278
310	0.1864
315	0.0839
320	0.0180
Total	**1.0000**

Statistical analysis

All measurements were performed in triplicate, and data are expressed as mean ± standard deviation. Statistical comparisons between formulations and between pre- and post-stability testing were performed using appropriate statistical tests. Differences were considered statistically significant at $p < 0.05$.

Results

Yield of simplicia and extract

The dried leaf powder (simplicia) of *A. bilimbi* yielded 35.22% from the fresh leaves, while the concentrated ethanolic extract yielded 14.57% from the dried powder. Both yields were in accordance with the standards specified in the Indonesian Herbal Pharmacopoeia.

Phytochemical screening

Qualitative phytochemical analysis of the *A. bilimbi* ethanolic extract revealed the presence of phenolic compounds, flavonoids, and tannins (Table 3). Phenolic compounds were confirmed by the formation of a green precipitate upon addition of 1% $FeCl_3$. Flavonoid presence was indicated by the development of yellow coloration after treatment with magnesium powder and concentrated HCl. Tannins were detected through the appearance of a greenish to black color following addition of 10% $FeCl_3$.

Organoleptic characteristics

Visual examination revealed that all gel formulations (F0 to F3) exhibited acceptable color, odor, and texture both before and after stability testing (Figure 1). The color intensity increased progressively with higher extract concentrations, ranging from transparent in F0 to dark brown in F3. All formulations displayed a characteristic herbal odor and semi-solid gel texture suitable for topical application.

Homogeneity test

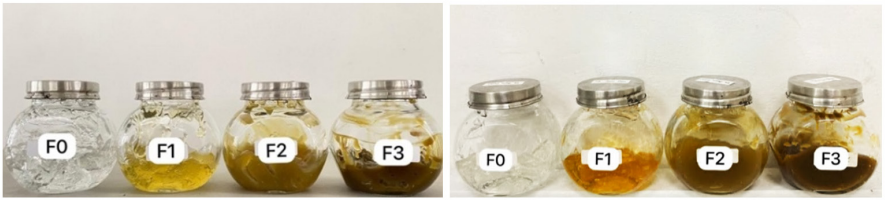
Microscopic examination of all gel formulations showed homogeneous dispersion without visible undissolved particles or phase separation, both before and after stability testing (Figure 2). This indicates uniform distribution of the extract throughout the gel matrix in all formulations.

pH measurement

The pH values of all formulations ranged from 4.5 to 7.0, falling within the acceptable range for topical

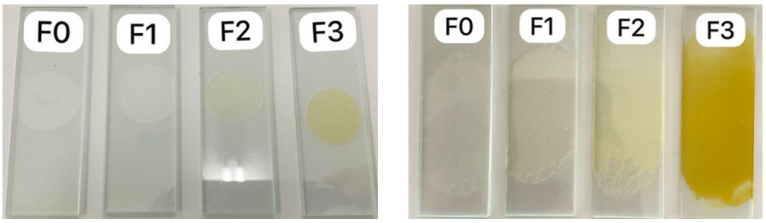
Table 3. Phytochemical screening results of *A. bilimbi* ethanolic leaf extract

Secondary metabolite	Reagent	Observation	Result	Image
Phenolic compounds	1% $FeCl_3$	Green precipitate formed	Positive (+)	
Flavonoids	Mg powder + HCl	Yellow color formed	Positive (+)	
Tannins	10% $FeCl_3$	Greenish to black color formed	Positive (+)	



(a) Before stability testing (b) after stability testing

Figure 1. Organoleptic appearance of sunscreen gel formulations containing different concentrations of *A. bilimbi* ethanolic extract. (a) Before stability testing, showing F0 (0%), F1 (0.2%), F2 (1%), and F3 (5%) from left to right. (b) After stability testing, demonstrating maintained appearance and consistency across all formulations.



(a) Before stability testing (b) after stability testing

Figure 2. Homogeneity assessment of sunscreen gel formulations. (a) Before stability testing and (b) after stability testing, showing uniform dispersion without particulate matter or phase separation across all formulations (F0 to F3). Images were captured by spreading gel samples between glass slides under transmitted light.

application (Figure 3A). An inverse relationship was observed between extract concentration and pH, with higher concentrations resulting in lower pH values. This pH reduction is attributable to the acidic nature of the *A. bilimbi* ethanolic extract (pH 5.26). Statistical analysis revealed no significant difference in pH values before and after stability testing ($p > 0.05$), indicating pH stability across all formulations.

Viscosity determination

Viscosity measurements demonstrated that all formulations met the acceptable range of 2,000 to 50,000 cps (Figure 3B). A decrease in viscosity was observed with increasing extract concentration, both before and after stability testing. Statistical analysis showed no significant difference in viscosity between pre-stability and post-stability samples ($p > 0.05$), confirming viscosity stability of the formulations.

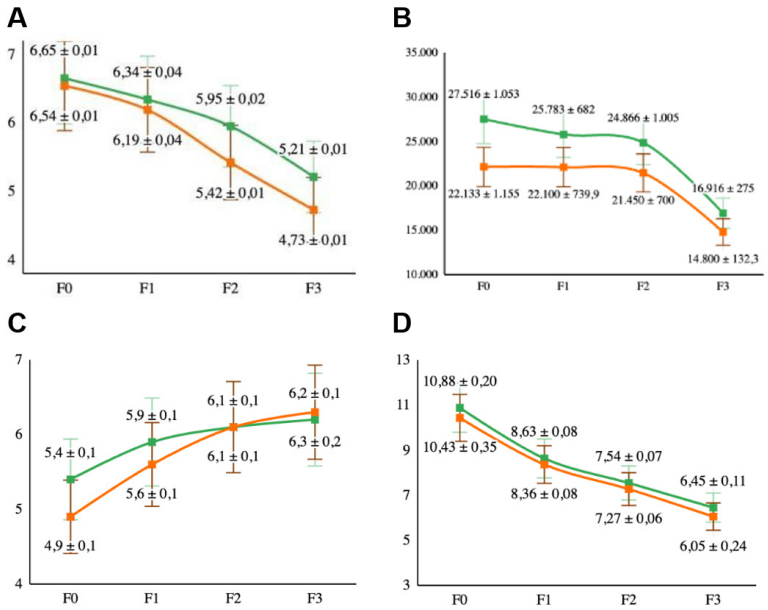


Figure 3. Physicochemical properties of sunscreen gel formulations before and after stability testing. (A) pH values decreased slightly with extract concentration, remaining within acceptable range (4.5–7.0). (B) Viscosity maintained acceptable values (2,000–50,000 cps) across formulations. (C) Spreadability increased with extract concentration. (D) Adhesiveness decreased with extract concentration but remained above minimum requirement (>1 second). Data: mean ± SD (n=3). F0 = 0%, F1 = 0.2%, F2 = 1%, F3 = 5% extract. Green line: before testing; orange line: after testing.

Spreadability test

The spreadability of gel formulations increased proportionally with extract concentration (Figure 3C). All formulations exhibited spreadability diameters within the acceptable range of 5 to 7 cm. The enhanced spreadability at higher extract concentrations is associated with the reduced viscosity of these formulations.

Adhesiveness test

Adhesiveness measurements revealed a decreasing trend with increasing extract concentration (Figure 3D). Statistical analysis indicated a significant difference between pre-stability and post-stability values ($p < 0.05$), suggesting reduced stability of adhesive properties. However, all formulations maintained adhesiveness values exceeding the minimum requirement of 1 second, thereby meeting the acceptable standard for topical gels.

SPF value determination

Spectrophotometric analysis demonstrated that SPF values increased proportionally with extract concentration (Figure 4). This correlation is attributed to the higher content of photoprotective secondary metabolites, particularly flavonoids and phenolic compounds, at elevated extract concentrations [9]. Among all formulations, F3 containing 5% *A. bilimbi* leaf extract exhibited the highest SPF value of 36.9, categorized as ultraprotection. F2 (1% extract) also achieved ultraprotection category, while F1 (0.2% extract) demonstrated maximum protection category.

Following accelerated stability testing, a reduction in SPF values was observed across all formulations (Figure 4). This decrease is likely attributed to thermal degradation of the photoprotective compounds in the *A. bilimbi* extract during exposure to cycling temperatures (4°C and 40°C). Despite this reduction, statistical analysis indicated no significant difference between pre-stability and post-stability SPF values ($p > 0.05$), suggesting acceptable stability of the photoprotective efficacy.

Discussion

This study successfully developed and characterized sunscreen gel formulations containing *A. bilimbi* ethanolic leaf extract at varying concentrations (0%, 0.2%, 1%, and 5%). The findings demonstrate that all formulations exhibited acceptable physicochemical properties, including organoleptic characteristics, homogeneity, pH, viscosity, spreadability, and adhesiveness, meeting the established standards for

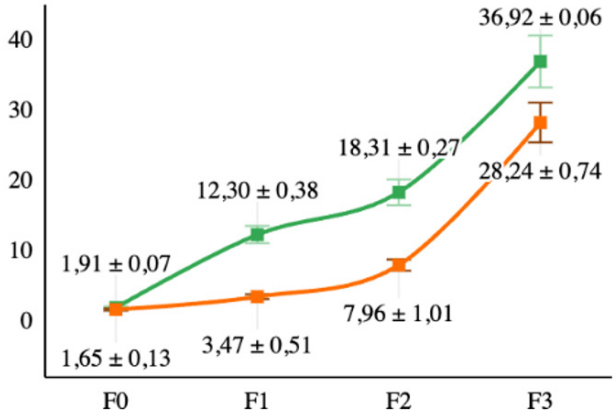


Figure 4. SPF values of sunscreen gel formulations before and after stability testing. SPF increased with extract concentration, with F3 (5% extract) showing highest photoprotection (SPF 36.9). A slight, non-significant decrease in SPF occurred after stability testing ($p > 0.05$). Data: mean ± SD (n=3). F0 = 0%, F1 = 0.2%, F2 = 1%, F3 = 5% extract. Dotted lines: SPF thresholds for maximum protection (15–30) and ultraprotection (>30). Green line: before testing; orange line: after testing.

topical gel preparations. Stability assessment revealed that pH, viscosity, spreadability, and SPF values remained stable under accelerated conditions, while adhesiveness showed reduced stability but maintained acceptable performance. The photoprotective efficacy, measured as SPF values, increased proportionally with extract concentration, with F1 achieving maximum protection and F2 and F3 reaching ultraprotection categories. These results establish a clear concentration-dependent relationship between *A. bilimbi* extract content and sunscreen effectiveness.

The organoleptic evaluation revealed progressive color intensification from transparent to dark brown with increasing extract concentration. This chromatic change is attributable to the tannin content in *A. bilimbi* leaves. Tannins are polyphenolic compounds that exhibit high solubility in polar solvents and characteristically impart brown coloration to solutions and formulations [13]. The maintained organoleptic consistency before and after stability testing indicates that the formulations are resistant to visual degradation under thermal stress, which is essential for product shelf life and consumer acceptance.

The inverse relationship between extract concentration and pH values observed in this study can be explained by the acidic nature of the *A. bilimbi* ethanolic extract (pH 5.26). As the proportion of extract increases in the formulation, the overall pH decreases accordingly. Despite this pH reduction, all formulations remained within the physiologically acceptable range of 4.5 to 7.0, which corresponds to the pH of human skin [12]. This pH compatibility is crucial for minimizing skin irritation and maintaining the skin barrier function during topical application. The stability of pH values throughout the accelerated aging test ($p > 0.05$) further confirms the formulation's resistance to pH drift under environmental stress.

The observed decrease in viscosity with increasing extract concentration presents an interesting rheological phenomenon. This reduction is likely caused by the pH-dependent swelling behavior of Carbopol 940, the gelling agent employed in this study. Carbopol polymers achieve optimal gelation and maximum viscosity at neutral to slightly alkaline pH through ionization of carboxyl groups and subsequent polymer chain expansion [12]. As the extract lowers the formulation pH, the degree of Carbopol ionization decreases, resulting in reduced polymer swelling and lower viscosity. Additionally, exposure to extreme temperatures during stability testing may compromise the three-dimensional network structure of Carbopol 940, further contributing to viscosity reduction [10]. Nevertheless, the viscosity of all formulations remained within the acceptable range of 2,000 to 50,000 cps, ensuring appropriate consistency for topical application.

The spreadability and adhesiveness properties exhibited inverse trends relative to viscosity changes. Higher extract concentrations, which correspond to lower viscosity, demonstrated enhanced spreadability. This relationship is consistent with fundamental rheological principles, as reduced internal resistance facilitates easier deformation and spreading of the gel matrix [12]. Conversely, adhesiveness decreased with increasing extract concentration and showed significant

variation after stability testing ($p < 0.05$). The reduced adhesiveness is attributed to the diminished ability of the gelling agent to maintain intermolecular cohesion at lower pH and after thermal stress [10,12]. However, it is important to note that despite the statistical variation, all formulations maintained adhesiveness exceeding 1 second, thereby satisfying the minimum requirement for topical gel preparations.

The accelerated stability testing using cycling test methodology provided valuable insights into the formulation behavior under thermal stress. The cycling between low (4°C) and high (40°C) temperatures simulates extreme storage conditions and accelerates potential degradation processes. While most physicochemical parameters demonstrated acceptable stability, the adhesiveness reduction suggests some structural changes in the gel network. This finding highlights the importance of optimizing storage conditions to maintain optimal product performance throughout the shelf life.

The observed decrease in SPF values following stability testing, although not statistically significant ($p > 0.05$), warrants careful consideration. Prolonged exposure to elevated temperatures may induce degradation of photoprotective compounds, particularly flavonoids and phenolic derivatives present in the *A. bilimbi* extract. Previous research has demonstrated that *A. bilimbi* ethanolic extracts are thermally sensitive and undergo degradation at temperatures exceeding 40°C [7]. The cycling test protocol employed in this study subjected the formulations to 40°C for extended periods, potentially compromising the stability of heat-labile bioactive compounds. This thermal sensitivity underscores the necessity for appropriate storage conditions and suggests that cold storage or the incorporation of stabilizing agents may be beneficial for maintaining photoprotective efficacy.

The concentration-dependent increase in SPF values represents the most significant finding of this investigation. The SPF values ranged from negligible protection in the control formulation (F0) to maximum protection in F1 (0.2% extract) and ultraprotection in F2 (1% extract) and F3 (5% extract, SPF 36.9). This dose-response relationship directly correlates with the concentration of photoprotective secondary metabolites in the formulations. The phytochemical screening confirmed the presence of flavonoids, phenolic compounds, and tannins, all of which possess UV-absorbing properties through their conjugated aromatic systems and chromophoric groups [9].

Flavonoids are particularly effective UV absorbers due to their aromatic ring structures with hydroxyl substituents, which enable efficient absorption of UV radiation in the 290 to 320 nm range. Phenolic compounds similarly contribute to photoprotection through their ability to absorb UV energy and dissipate it through non-radiative decay processes. The presence of these compounds in higher concentrations within F2 and F3 explains their superior photoprotective performance. Additionally, these phytochemicals may exert antioxidant effects by scavenging reactive oxygen species generated during UV exposure, providing a dual mechanism of skin protection.

The findings of this study suggest that formulation F3, containing 5% *A. bilimbi* ethanolic extract, offers the highest photoprotective efficacy with an SPF value of 36.9, categorizing it as ultraprotection. However, practical formulation decisions must balance efficacy with other considerations such as aesthetic properties, stability, and cost-effectiveness. The lower viscosity and adhesiveness observed in F3 may affect consumer perception and product performance during application. Furthermore, the darker brown coloration resulting from higher tannin content might be cosmetically less acceptable to certain consumer segments.

Formulation F2, containing 1% extract, presents a potentially optimal compromise, achieving ultraprotection (SPF >30) while maintaining more favorable physicochemical properties compared to F3. The selection between F2 and F3 would depend on the intended product positioning and target consumer preferences. For applications requiring maximum photoprotection, such as beach or sports formulations, F3 would be preferable. For daily-use cosmetic products where aesthetic properties are prioritized, F2 may offer better overall performance.

The development of natural sunscreen agents has gained considerable attention due to growing consumer preference for plant-based cosmetic products and concerns regarding the safety and environmental impact of synthetic UV filters. The present study contributes to this field by demonstrating that *A. bilimbi* leaf extract can serve as an effective natural photoprotective agent. While previous research has explored various topical applications of *A. bilimbi* extracts, including bath soaps, antioxidant creams, and peel-off masks [5], this investigation represents the first systematic evaluation of gel formulations specifically designed for sunscreen applications.

The photoprotective efficacy demonstrated in this study positions *A. bilimbi* extract as a competitive natural alternative to synthetic UV filters. However, it is important to acknowledge that natural photoprotective agents typically require higher concentrations to achieve SPF values comparable to synthetic compounds. This concentration dependency must be balanced against potential skin sensitization, color interference, and formulation stability challenges that may arise at elevated extract levels.

While these results are promising, several areas require further investigation. Formulation strategies such as microencapsulation or antioxidant stabilizers should be explored to enhance thermal stability. Comprehensive safety evaluations, including skin irritation and sensitization tests, are needed before clinical use. Long-term stability studies under real-world conditions would better predict shelf life than accelerated testing.

Future research should assess broad-spectrum photoprotection, including UV-A defense not evaluated here. Clinical studies with human subjects are needed to confirm in vivo efficacy. Additionally, optimizing the gel base to improve adhesiveness at higher extract concentrations could enhance overall formulation performance.

Conclusion

This study demonstrates that sunscreen gel formulations containing *A. bilimbi* ethanolic leaf extract exhibit acceptable physicochemical properties and concentration-dependent photoprotective efficacy. Formulations with 1% and 5% extract achieved ultraprotection (SPF >30), establishing *A. bilimbi* as a promising natural sunscreen ingredient. Stability testing revealed generally stable physicochemical parameters, though thermal sensitivity of photoprotective compounds indicates the need for optimized storage conditions. These findings provide a foundation for developing natural, plant-based sunscreen products and highlight the potential of *A. bilimbi* leaf extract in cosmetic photoprotection applications.

Acknowledgements

The authors thank all those who contributed to this study.

Funding

None.

Author contributions

Conceptualization, RGW; Methodology and investigation, RGW and AMR; Data curation, RGW and UKSR; Formal analysis and writing—original draft, RGW; Writing—review and editing, RGW, AMR, and UKSR; Supervision, AMR.

Declaration of interest

The authors declare no competing interests.

Received: October 27, 2025
Revised: November 15, 2025
Accepted: November 16, 2025
Published: December 31, 2025

References

1. D'Orazio J, Jarrett S, Amaro-Ortiz Alexandra and Scott T. UV radiation and the skin. Int J Mol Sci. 2013;14: 12222-12248. https://doi.org/10.3390/ijms140612222
2. Setiabudi J, Indira IGAAE, Puspawati NMD. Profil pra kanker dan kanker kulit di RSUP Sanglah periode 2015-2018. E-j med udayana. 2021;10: 83. https://doi.org/10.24843/MU.2021.V10.i3.P13
3. Alyyu N, Fuadah YN, Pratiwi NKC. Klasifikasi kanker kulit ganas dan jinak menggunakan metode convolutional neural network. Proceeding of Engineering. 2022;8: 3200-3206.
4. Wiraningtyas A, Ruslan R, Agustina S, Hasanah U. Penentuan Nilai Sun Protection Factor (SPF) dari Kulit Bawang Merah. Jurnal redoks (jurnal pendidikan kimia dan ilmu kimia). 2019;2: 34-43. https://doi.org/10.33627/re.v2i01.140
5. Ariem F, Yamlean PVY, Lebang JS. Formulasi dan uji efektivitas antioksidan sediaan krim ekstrak etanol daun belimbing wuluh (averrhoa bilimbi l.) dengan menggunakan metode dpph (1,1-diphenyl-2-picrylhydrazyl). PHARMACON. 2020;9: 501. https://doi.org/10.35799/pha.9.2020.31355
6. Fatmawaty A, Nisa M, Riski R. Teknologi Sediaan Farmasi. Yogyakarta: DeePublish; 2015.
7. Andriani M, Permana IDGM, Widarta IWR. The effect of time and temperature extraction on antioxidant activity of starfruit wuluh leaf (Averrhoa bilimbi L.) using ultrasonic assisted extraction (UAE) method. Ilmu dan Teknologi Pangan. 2019;8: 330-340.
8. Harborne JB. Phytochemical Methods:A guide to modern techniques of plant analysis. 3rd ed. London: Chapman & Hall; 1998.
9. Buang A, Adriana ANI, Pasimak VJ. Formulasi gel tabir surya ekstrak daun teh hijau (Camelia sinensis)

dan penentuan nilai sun protection factor (SPF). Jurnal Kesehatan Yamasi Makassar. 2021;5: 77-86.

10. Thomas NA, Tungadi R, Hiola F, S. Latif M. Pengaruh Konsentrasi Carbopol 940 Sebagai Gelling Agent Terhadap Stabilitas Fisik Sediaan Gel Lidah Buaya (Aloe Vera). Indonesian Journal of Pharmaceutical Education. 2023;3. https://doi.org/10.37311/ijpe.v3i2.18050
11. Tan V, Rahmadhani NT, Dewi IP. formulasi ekstrak kloroform daun belimbing wuluh dalam bentuk sediaan gel dan uji aktivitas antibakteri terhadap Staphylococcus epidermidis. Jurnal Riset Kefarmasian Indonesia. 2019;1: 203-209. https://doi.org/10.33759/jrki.v1i3.54
12. Agustiani FRT, Sjahid LR, Nursal FK. Kajian Literatur : Peranan Berbagai Jenis Polimer Sebagai Gelling Agent Terhadap Sifat Fisik Sediaan Gel. Maj Farmasetika. 2022;7: 270. https://doi.org/10.24198/mfarmasetika.v7i4.39016
13. Warnasih S, Hasanah U. Phytochemical Characterization And Tannin Stability Test From Kluwek (Pangium edule Reinw). Journal of Science Innovare. 2019;1: 44-49. https://doi.org/10.33751/jsi.v1i02.1000