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Formulation and Antistaphylococcal Activity of Alpinia galanga (L.) Extract Lotion

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ABSTRACT:

Background and Objectives: The global increase in antimicrobial resistance among clinical strains of Staphylococcus aureus has severely compromised the efficacy of conventional topical antibiotic therapies. Staphylococcus aureus remains a primary bacterial pathogen responsible for a wide spectrum of cutaneous infections, including impetigo, folliculitis, furuncles, and primary abscesses. Moreover, research attention has shifted toward bio-prospective medicinal plants to develop safe, effective, and natural topical cosmeceuticals. Alpinia galanga (L.) Sw. (Zingiberaceae), commonly known as galangal or Siamese ginger, is a traditional Asian medicinal plant whose rhizomes possess potent antibacterial, anti-inflammatory, and antioxidant properties driven by diverse secondary metabolites. Despite known antimicrobial activity of A. galanga extracts, limited scientific research exists regarding its systematic incorporation into stable topical lotion emulsions and the subsequent impact of extract loading on delivery vehicle stability and bioactive release. Therefore, this study aimed to formulate an Alpinia galanga rhizome extract-based oil-in-water (o/w) topical lotion at varying concentrations (25%, 50%, and 75% w/w), systematically evaluate its physicochemical quality control parameters (pH, viscosity, spreadability, organoleptic features, and emulsion type), and determine its in-vitro antistaphylococcal efficacy to identify the optimal therapeutic concentration threshold.

Methodology: Processed A. galanga rhizomes were shade-dried for four days and subjected to cold maceration using 95% ethanol. The liquid extract was concentrated under reduced pressure using a rotary evaporator, and the percentage crude yield was calculated relative to the initial dry biomass weight. The crude extract underwent baseline physicochemical characterization (pH, color, odor, taste, appearance, and solubility across solvents) and qualitative phytochemical screening for flavonoids, phenols, tannins, alkaloids, glycosides, saponins, and proteins using standard colorimetric protocols. An oil-in-water (o/w) lotion base was prepared by heating the oil phase (stearic acid, coconut oil) and aqueous phase (distilled water, xanthan gum, triethanolamine) independently to 75 °C, followed by continuous mechanical agitation to generate an in-situ stearate soap network reinforced by an anionic polymer. Additional excipients (glycerin, titanium dioxide, preservatives, essential oil fragrances) were incorporated upon cooling. Crude A. galanga extract was incorporated at 25%, 50%, and 75% (w/w) formulations. It were then evaluated for organoleptic characteristics, emulsion type via the water dilution test, pH

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using a 10% aqueous dispersion, viscosity using a rotary viscometer (25 rpm), and spreadability via the parallel plate method applying a 500 g weight. In-vitro antibacterial activity against Staphylococcus aureus was evaluated using the agar well diffusion method, comparing the test lotions against a positive control (2% fusidic acid cream) and a negative control (unadulterated lotion base) after 19 hours of incubation at 37 °C. Zones of inhibition were measured in millimeters using a digital Vernier caliper, and mean differences were evaluated statistically using Tukey's post-hoc test.

Main Results: Maceration of 700.0 g of dried rhizome yielded 21.5 g of crude ethanolic extract, corresponding to a percentage yield of 3.07%. The extract was a dark brown, viscous semi-liquid with an aromatic odor, bitter taste, and near-neutral pH of 6.57. It was soluble in water, sparingly soluble in ethanol, and insoluble in hexane. Phytochemical screening confirmed the presence of flavonoids, alkaloids, phenols, glycosides, and saponins, while testing negative for tannins and proteins. All formulated lotions maintained a uniform citrus-mint aroma, complete physical homogeneity, and an oil-in-water emulsion structure. Increasing extract concentration caused the lotion pH to drop from 6.73 (25% AG) to 5.91 (50% AG) and 5.68 (75% AG), remaining within safe skin physiological limits. Viscosity exhibited a non-linear decline from 42.80 mPa·s at 25% loading to 36.20 mPa·s at 50% loading, followed by a severe matrix collapse to 9.88 mPa·s at 75% loading. Spreadability demonstrated a parabolic trend, measuring 28.36 mm (25% AG), 33.36 mm (50% AG), and 28.33 mm (75% AG). In the antibacterial assay, the 25% AG lotion demonstrated potent inhibition against S. aureus with a mean zone of inhibition of 22.40 mm, which was statistically equivalent to 2% fusidic acid (21.70 mm, $p > 0.05$). On the other hand, the 50% AG lotion (13.30 mm) and 75% AG lotion (11.70 mm) showed significantly reduced activity, performing statistically no better than the untreated lotion base (12.80 mm).

Conclusions: The 25% A. galanga lotion is the optimal, stable, and therapeutically effective formulation for topical application against S. aureus infections. Exceeding a 25% extract concentration causes chemical overload from acidic phytoconstituents and electrolytes, which neutralizes the electrical charges of the xanthan gum polymer and breaks down the stearate soap matrix. This physical vehicle collapse leads to micellar entrapment, physically locking bioactive compounds within the formulation and preventing their diffusion into target tissues. Future research should explore non-ionic gel networks, advanced extraction methods (such as microwave-assisted extraction), and quantitative chromatographic profiling.

INTRODUCTION

In recent years, the global cosmetic and pharmaceutical industries have experienced a shift toward herbal-based formulations. About one-third of the top-selling products in the pharmaceutical industry are natural products which are either derived from plants or microorganisms. These products are highly preferred due to its unique advantages of good therapeutic efficacy, low side effects and cheaper than synthetic products (Elkordy et al., 2021). *Staphylococcus aureus* is the most common pathogen involved in skin infections worldwide, regardless of the patient's age, the climate or geographical area. *S. aureus* skin infections include impetigo, folliculitis, furuncles, and primary abscesses. Secondary skin infections are those occurring as a consequence of a pre-existing cutaneous lesion (Del Giudice, 2020). And thus, the steady rise of antimicrobial resistance (AMR) among clinical staphylococcal strains has severely compromised the efficacy of standard topical antibiotics (Kumar et al., 2025). Moreover, there is an ongoing need to explore bio-prospective medicinal plants to develop novel, safe, and effective natural topical therapies.

Alpinia galanga (L.) Sw. (*Zingiberaceae*) is commonly known by various names as galangal, greater galangal, Java galangal and Siamese ginger (English). Galangal is a native of Indonesia though the exact origin is not known, but has become naturalized in many parts of South and South-East Asian countries.

Alpinia galanga serves as an important medicinal plant in traditional systems of medicine to treat several ailments, including microbial infections, inflammations, rheumatic pains, fever, and metabolic disorders (Aziz et al., 2024; Tian et al., 2022). Its rhizomes contain enzymes, polysaccharides, and secondary metabolites that exhibit potent antibacterial effects against Gram-positive pathogens, particularly *Staphylococcus aureus* and *Streptococcus* species. These therapeutic properties are mediated by diverse phytochemicals acting individually or synergistically within the botanical matrix (Aziz et al., 2024).

The rhizomes of galangal are taken for their stimulatory, expectorant, and carminative properties, while topical formulations and oil preparations are applied externally for wound healing, easing rheumatic inflammation, and managing scalp conditions like dandruff (Tian et al., 2022). Furthermore, essential oils and extracts obtained from fresh and dried rhizomes of *A. galanga* demonstrate strong antimicrobial activity against Gram-positive bacterial pathogens (Destryana et al., 2024).

Despite the known antimicrobial properties of *A. galanga*, research focusing on its systematic development into stable cosmetic emulsions, alongside an evaluation of how it impacts its bioactivity, remains limited. Therefore, this study was conducted to formulate an *A. galanga* rhizome extract-based topical lotion at varying concentrations (25%, 50%, and 75%). Furthermore, this study aimed to systematically evaluate the physicochemical quality parameters of these formulations, including pH, viscosity, and spreadability, and determine their in-vitro antistaphylococcal efficacy against *Staphylococcus aureus* to identify the optimal therapeutic formulation threshold.

METHODOLOGY

Plant Preparation and Ethanolic Extraction

The collected *Alpinia galanga* rhizomes were thoroughly washed under running water, shade-dried for four days, and mechanically chopped. The prepared plant material was extracted using 95% ethanol as the solvent. The resulting liquid was then concentrated under reduced pressure utilizing a rotary evaporator until the solvent was fully evaporated (Subash et al, 2013). The extraction efficiency, or percentage yield, was determined by calculating the ratio of the final crude extract weight to the initial weight of the dried sample.

Physicochemical and Phytochemical Evaluation

The crude extract underwent baseline physical evaluations to document its odor, color, taste, appearance, solubility, and pH. Subsequently, qualitative phytochemical screening was conducted following standard analytical protocols to identify the presence of specific secondary metabolites:

- **Flavonoids:** The extract (1 mL) was treated with 1 mL of sodium hydroxide (NaOH). The formation of a yellow precipitate indicated a positive result (Hosea et al, 2018).
- **Phenols (Ferric Chloride Test):** The extract (1 mL) was mixed with 1 mL of 10% ferric chloride. The formation of a greenish-brown precipitate denoted the presence of phenols (Hosea et al, 2018).
- **Tannins:** The extract (5 mL) was added to 2 mL of 1% hydrochloric acid (HCl). The deposition of a red precipitate confirmed the presence of tannins (Hosea et al, 2018).
- **Alkaloids (Dragendorff's Test):** A 0.2 g extract sample was boiled with 5 mL of 2% HCl on a steam bath. The mixture was filtered, and the filtrate was treated with two drops of Dragendorff's Reagent. A red precipitate indicated a positive result (Subash et al, 2013).
- **Glycosides:** The extract (0.1 g) was boiled with 5 mL of diluted sulfuric acid in a water bath for 15 minutes, cooled, and neutralized with a 20% potassium hydroxide solution. An equal mixture of Fehling's solutions A and B was added and boiled for 5 minutes. A dense red precipitate confirmed the presence of glycosides (Subash et al, 2013).
- **Saponins (Frothing Test):** Extract filtrate (1 mL) was diluted with 4 mL of distilled water and shaken vigorously. The formation of a stable, persistent froth upon standing indicated the presence of saponins (Subash et al, 2013).
- Proteins (Ninhydrin Test): The extract solution (1 mL) was mixed with Ninhydrin reagent and heated in a water bath. The formation of a blue or violet precipitate indicated the presence of proteins (Subash et al, 2013).

- Proteins (Biuret Test): The extract (2 mL) was treated with five drops of 1% hydrated copper sulfate, followed by the addition of 2 mL of 40% sodium hydroxide. The mixture was shaken vigorously, with the appearance of a purple discoloration denoting a positive result for proteins (Subash et al, 2013).

Formulation of the Lotion

The base formulation was developed as an oil-in-water (o/w) emulsion. To safeguard intellectual property for pending patent protection, composition parameters are reported as functional concentration ranges (% w/w). The composition and pharmaceutical functions of the base components are detailed in Table 1.

Table 1. Composition and pharmaceutical functions of the components in the experimental lotion base (150 g batch size).

Component	Concentration Range (% w/w)	Functional Category
Distilled Water	70.0 – 85.0	Aqueous Vehicle / Continuous Phase
Coconut Oil	5.0 – 10.0	Oleaginous Phase / Emollient
Glycerin	2.0 – 5.0	Humectant
Stearic Acid	1.0 – 4.0	Structuring Agent / Emulsifying Lead
Triethanolamine (TEA)	1.0 – 3.0	Alkalizing Agent / Neutralizer
Xanthan Gum	0.5 – 2.0	Viscosity Modifier / Polymeric Stabilizer
Titanium Dioxide	0.1 – 0.5	Opacifying Agent
Methylparaben	0.05 – 0.2	Antimicrobial Preservative
Ethylenediaminetetraacetic Acid (EDTA)	0.05 – 0.2	Chelating Agent
Lemon Oil & Peppermint Oil	< 0.5	Fragrance / Masking Agents

The oil phase components (stearic acid and coconut oil) and aqueous phase constituents (distilled water, xanthan gum, and triethanolamine) were heated independently to 75 °C. The phases were combined at temperature under continuous mechanical agitation to generate the in-situ stearate soap network. The mixture was stirred continuously as it cooled to room temperature to establish a stable oil-in-water emulsion. Glycerin, titanium dioxide, methylparaben, EDTA, and the essential oil fragrances were then incorporated into the cooled base under steady mixing until physical homogeneity was achieved. The prepared lotion base served as the vehicle to incorporate varying concentrations (25%, 50%, and 75% w/w) of the crude *Alpinia galanga* ethanolic extract (Rasheed et al., 2012).

Physicochemical Evaluation and Quality Control

- **Organoleptic Assessment and Emulsion Type:** Physical properties including color, odor, and homogeneity were evaluated organoleptically. Emulsion type (oil-in-water) was confirmed using the water dilution test (Gyawali et al., 2016).
- **pH Determination:** Formulations were evaluated using a calibrated digital pH meter. A 10% (w/v) aqueous dispersion of the lotion was prepared, and the electrode was immersed into the sample to record the pH.
- **Viscosity:** Rheological behavior was evaluated using a rotary viscometer. The spindle was directly immersed into the formulation, and viscosity measurements were recorded at a rotation speed of 25 rpm.
- **Spreadability:** Determined using the parallel plate method. A 0.2 g sample was placed in the center of a 90 mm circular glass plate and covered with a matching glass plate. A 500 g weight was applied to the upper plate to press the lotion into a uniform layer. The weight was removed, and the total spread diameter was measured in millimeters.

Antibacterial Assay

McFarland Standards are used to standardize the approximate number of bacteria in a liquid suspension by comparing the turbidity of the test suspension with that of the McFarland Standard. A McFarland Standard is a chemical solution of barium chloride and sulphuric acid; the reaction between these two chemicals results in the production of a fine precipitate, barium

sulphate. When shaken well, the turbidity of McFarland Standard is visually comparable to a bacterial suspension of known concentration (Hosea et al, 2018)

Procedure:

One gram (1g) of Barium Chloride was weighed and dissolved in 99mL of distilled water to get 1% BaCl2. 1 ml of Concentrated Sulfuric acid was dissolved in 99 mL of distilled water to get 1% H2SO4. 9.95mL of 1% H2SO4 was dissolved in 0.05mL (50mcL) of 1%BaCL2, the solution was dissolved with a stirring rod to become turbid. The isolate was dissolved with the turbidity of the McFarland standard (Hosea et al, 2018).

Sensitivity test

The sensitivity test of the plant extract was determined using agar well diffusion method. The Staphylococcus aureus isolate was dissolved in normal saline to compare with McFarland standard. The S. aureus were first grown on Mueller-Hinton Agar. Then, a hole with a diameter of 6 to 8mm were punched aseptically with a sterile cork borer, and a volume (20-100mcL) of the cream, positive control, and negative control were introduced into the well. Then, agar plates were incubated under 37 degrees Celsius at 19 hours. The zones of inhibition was determined using a digital Vernier caliper and have the following inferences (Guevarra, 2005):

- <10mm expressed as inactive
- 10-13 mm partially active
- 14-19 mm active
- >19mm very active

RESULTS

Percentage yield of AG

Table 2 Material throughput and percentage yield of Alpinia galanga ethanolic extraction.

Parameter	Value
Initial Weight of Dried Rhizome Sample (g)	700.0
Final Weight of Crude Ethanolic Extract (g)	21.5
Percentage Crude Yield (%)	3.07%

The solvent extraction of *Alpinia galanga* rhizomes utilizing ethanol yielded a concentrated, dark crude extract. Out of an initial starting mass of 700.0 g of processed, dried raw material, a total of 21.5 g of crude phytoconstituents was recovered after solvent evaporation. The mathematical calculation for the extraction efficiency is expressed through the following formula:

$$\text{Percentage Yield (\%)} = \left(\frac{\text{Weight of Crude Extract (g)}}{\text{Weight of Dried Sample (g)}} \right) \times 100$$

Based on this relationship, the final crude percentage yield for the *A. galanga* rhizome was determined to be 3.07%.

Physical test of AG extract

Table 3. Physical Test of the A. galanga extract

Parameter Category	Physical Test Property	Observation / Characteristics
Organoleptic	Odor	Aromatic, sweet-smelling
	Color	Dark brown
	Taste	Bitter
	Appearance / State	Viscous, syrupy semi-liquid
Physicochemical	pH	6.57
	Solubility (Hexane)	Insoluble

Solubility (Water)	Soluble
Solubility (Ethanol)	Sparingly soluble

The organoleptic and physicochemical profile of the crude *Alpinia galanga* rhizome extract revealed distinct sensory and chemical characteristics (Table 3). Physically, the extract recovered was a highly viscous, syrupy semi-liquid displaying a dark brown coloration, a characteristically sweet aroma, and a distinctly bitter taste. Physicochemical testing demonstrated that the crude extract had a near-neutral, weakly acidic pH of 6.57. Qualitative solubility profiles indicated a strongly polar character; the extract was completely insoluble in the non-polar solvent hexane, highly soluble in polar distilled water, and only sparingly soluble in organic ethanol.

Chemical test

Table 4 Qualitative phytochemical screening of crude Alpinia galanga rhizome extract.

Phytochemical Target	Reference Positive Result	Observed Experimental Result	Inference
Flavonoids	Yellow precipitate	Dark yellow coloration / precipitate	+
Alkaloids	Red precipitate	Dark precipitate in yellow solution	+
Phenols	Greenish-brown precipitate	Greenish-dark brown precipitate	+
Tannins	Red precipitate	Greenish-black precipitate	-
Glycosides	Dense red precipitate	Red-brown precipitate suspended in green solution	+
Saponins	Persistent, stable froth	Froth formation above the surface layer	+
Proteins			
- *Biuret Test*	Purple precipitate	Green-yellow precipitate	-
- *Ninhydrin Test*	Blue or violet precipitate	Yellow precipitate	-

Note: (+) indicates presence of the phytochemical group; *(-)* indicates absence.

Qualitative phytochemical screening of the crude ethanolic extract of *Alpinia galanga* rhizomes revealed a diverse profile of secondary metabolites (Table 4). The chemical screenings yielded distinctly positive results for five major classes of bioactive compounds: flavonoids, alkaloids, phenols, glycosides, and saponins. The presence of flavonoids was indicated by a prominent dark yellow precipitate, while alkaloids were verified via the formation of a dark precipitate suspended within a yellow solution matrix. Phenolic groups were confirmed by a characteristic greenish-dark brown precipitate. Glycoside analysis revealed a distinct red-brown precipitate suspended within a green solution phase, and saponin content was confirmed via the observation of an independent, persistent layer of foam or froth generated above the solution level. Moreover, the extract tested completely negative for both tannins (yielding an uncharacteristic greenish-black precipitate) and proteins (failing to produce the standard color shifts during both the Biuret and Ninhydrin colorimetric tests). The chemical test showed presence of flavonoids, alkaloids, phenols, glycoside, and saponins.

Quality test of AG lotion

Table 5 Physicochemical and organoleptic quality control profiles of formulated Alpinia galanga lotions at varying concentrations.

Quality Evaluation Parameter	25% AG Lotion	50% AG Lotion	75% AG Lotion
Color	Light brown	Light brown	Dark brown
Odor	Citrus-mint	Citrus-mint	Citrus-mint
Homogeneity	Homogeneous	Homogeneous	Homogeneous
pH	6.73	5.91	5.68
Viscosity (mPa·s)	42.80	36.20	9.88
Spreadability (mm)	28.36	33.36	28.33
Emulsion Type	Oil-in-water	Oil-in-water	Oil-in-water

Physicochemical and organoleptic quality control monitoring revealed distinct dose-dependent variations among the three experimental *Alpinia galanga* (AG) lotion concentrations (Table 5). Organoleptically, all formulations successfully maintained a uniform citrus-mint aroma driven by the essential oil additives, while the baseline color shifted progressively from a light brown hue at 25% and 50% loadings to a dense dark brown shade at the maximum 75% loading. All formulations exhibited excellent physical homogeneity with zero macro-scale separation, and uniformly preserved their structural classification as oil-in-water (o/w) emulsions.

However, numerical variations were highly pronounced across the physicochemical metrics. As the extract concentration escalated from 25% to 75%, the formulation pH dropped steadily from a near-neutral 6.73 down to a weakly acidic 5.68. Concurrently, a non-linear reduction in formulation viscosity was recorded, plummeting from 42.80 mPa·s (25% AG) to 36.20 mPa·s (50% AG), before undergoing a severe drop to 9.88 mPa·s at the 75% concentration. The structural spreadability profiles demonstrated a non-linear parabolic trend, expanding from an initial 28.36 mm at 25% loading to a maximum diameter of 33.36 mm at 50% loading, before contracting back to 28.33 mm at the 75% extraction threshold. The odor of *A. galanga* lotion is citrus-mint which came from the essential oils added to the formulated lotion to increase its appeal. For the viscosity, 25% AG lotion is the most viscous among the formulations because of higher amount of lotion base. Fifty percent (50%) AG lotion showed the highest spreadability which indicates that it can cover wider skin surface area than other formulated AG lotion.

All formulations were dissolved in water which indicates that the type of emulsion is oil-in-water. Oil-in-water emulsion or lotions are greaseless and washable by water as it has more water than oil.

Antibacterial assay

Table 6 Antibacterial Assay of A. galanga Lotion

Experimental / Control Group	Trial 1 (mm)	Trial 2 (mm)	Trial 3 (mm)	Mean Zone of Inhibition (mm)
Positive Control (2% Fusidic Acid)	20.40	22.30	22.30	**21.70[a]**
Negative Control (Lotion Base)	13.20	12.00	13.20	**12.80[b]**
25% AG Lotion	21.80	22.90	22.60	**22.40[a]**
50% AG Lotion	15.40	13.30	11.30	**13.30[b]**
75% AG Lotion	13.90	11.00	10.10	**11.70[b]**

Note: Mean values sharing identical superscript letters ([a]or[b]) indicate no statistically significant difference ($p>0.05$) according to Tukey's post-hoc analysis.

The quantitative in-vitro antibacterial assays demonstrated distinct, non-linear variations in the zone of inhibition metrics against Staphylococcus aureus across the different groups (Table 6). The 25% Alpinia galanga (AG) lotion displayed a prominent inhibitory effect, recording a maximum mean zone of inhibition of 22.40 mm. Statistical evaluation via post-hoc analysis confirmed that the performance of the 25% AG lotion shared the same statistical superscript (a) as the commercial positive control (2% Fusidic acid, mean = 21.70 mm), establishing that there is no statistically significant difference ($p > 0.05$) in antibacterial efficacy between these two groups. However, a drop in zone diameter was observed at higher extract loadings. The 50% AG lotion and 75% AG lotion yielded dramatically reduced mean zones of 13.30 mm and 11.70 mm, respectively. This indicates that increasing the crude extract concentration beyond 25% induced an inverse relationship, failing to increase bacterial inhibition and matching the baseline values of the unadulterated delivery vehicle.

Table 5 shows the antistaphylococcal activity of AG lotion in different concentrations. Both positive control and 25% AG had a very active inhibitory effect to *Staphylococcal aureus* while the negative control, 50% AG lotion and 75% AG lotion had a partially active inhibitory effect. Twenty-five percent (25%) AG lotion showed a comparable antibacterial activity of the positive control, Fucidic acid (Fucidin) 2% cream. There is no significant difference between the 50% AG lotion, 75% AG lotion and Negative control (lotion base). Results show that there is a decrease of antibacterial activity in relation to the increase of AG extract. This could be due to the interaction of AG extract constituents to the lotion base.

DISCUSSION

The crude extract yield of 3.07% (21.5 g recovered from 700.0 g of dried raw material) falls within the expected baseline range for conventional cold maceration of *Zingiberaceae* rhizomes. The four-day shade-drying pre-treatment effectively reduced moisture content to prevent enzymatic degradation and microbial spoilage, while protecting heat-sensitive secondary metabolites, such as flavonoids and phenolic compounds, from thermal destruction. However, this low percentage yield shows the inherent limitations of passive cold maceration. To optimize extraction efficiency and maximize the recovery of active compounds in future formulations, modern techniques should be explored. Recent studies on related *Zingiberaceae* species demonstrate that advanced methods, such as microwave-assisted extraction (MAE), successfully disrupt cellular structures using targeted energy. This approach bypasses the slow limits of traditional soaking, resulting in a significantly higher and faster yield of bioactive compounds (Botero et al., 2024; Gonzalez-Gonzalez et al., 2023).

Evaluating the organoleptic and physicochemical properties of the crude extract provides essential baseline data regarding its purity and compatibility with topical delivery systems. Recent formulation studies establish that physical observations, such as color, consistency, and odor, are primary indicators of an extract's chemical composition and physical stability (Nursal et al., 2024). The dark brown color and viscous, syrupy semi-liquid state signify a concentrated mixture of plant pigments (such as carotenoids and chlorophyll breakdown products), plant resins, and polar carbohydrates. The aromatic, sweet-smelling odor is driven by volatile essential oil constituents native to *Alpinia galanga* rhizomes, such as 1,8-cineole and fenchyl acetate, while the distinctly bitter taste confirms the presence of concentrated secondary metabolites, including alkaloids, saponins, and glycosides.

From a formulation perspective, the extract's pH of 6.57 is ideal for topical application. Sitting near neutral, it aligns comfortably with the pH window of human skin, which ranges from pH 4.0 to 7.0. Formulating within this specific acidic-to-neutral range is important for maintaining skin barrier integrity and minimizing the risk of cutaneous irritation or chemical dermatitis (Fernandez et al., 2026). The solubility profile further demonstrates that the bioactive constituents are predominantly polar and hydrophilic, being completely soluble in water, sparingly soluble in ethanol, and insoluble in non-polar hexane. As highlighted in pharmaceutical formulation research, this inherent polarity is a major determinant in phytomedicine development, as it directly dictates how the plant extract will partition and stabilize within the continuous phase of an oil-in-water (o/w) emulsion matrix (Jahangir et al., 2022).

Qualitative screening confirmed the presence of flavonoids, alkaloids, phenols, glycosides, and saponins, while testing negative for tannins and proteins. These secondary metabolites function synergistically against Gram-positive bacteria like *Staphylococcus aureus*. Phenols and flavonoids possess free hydroxyl (-OH) groups that complex with bacterial cell wall proteins, disrupt membrane integrity, and inhibit essential metabolic enzymes (Chukwunwejim et al., 2026). Alkaloids and glycosides intercalate with bacterial nucleic acids, interrupting DNA replication and cell division pathways (Omojate et al., 2014). Furthermore, saponins act as natural amphiphilic surfactants that intercalate directly into lipophilic cell membranes, increasing cell permeability, inducing leakage of intracellular contents, and ultimately causing cell lysis (Dong et al., 2020).

In addition to the therapeutic benefits, the specific absence of tannins and proteins is highly advantageous for a topical cosmetic formulation. High tannin concentrations act as strong astringents that can cause skin tightness, excessive dryness, or localized irritation upon application. Furthermore, the complete absence of proteins ensures the formulation lacks a viable nutrient substrate that could otherwise support opportunistic microbial spoilage, thereby enhancing the product's physicochemical stability and overall shelf-life (Nursal et al., 2024).

All formulations successfully maintained a citrus-mint aroma, complete homogeneity, and an oil-in-water (o/w) emulsion structure. However, higher extract concentrations darkened the formulation and induced dose-dependent physicochemical changes. The pH decreased progressively from 6.73 (at 25% loading) to 5.68 (at 75% loading) due to the accumulation of acidic phytoconstituents. Importantly, all pH values remained well within the safe physiological range for human skin (pH 4.0–6.5), which is a baseline to ensure topical formulations do not disrupt the skin's natural acid mantle.

Increasing the extract concentration also triggered significant changes. Viscosity dropped from 42.80 mPa·s at 25% to just 9.88 mPa·s at 75%. Moreover, spreadability showed a parabolic curve, peaking at 33.36 mm at 50% loading before dropping back down at 75%. This stems from interactions between the plant extract and the emulsion matrix. The formulation relies on an in-situ soap network (stearic acid and triethanolamine) reinforced by xanthan gum, an anionic polymeric stabilizer that uses negative electrical charges to maintain an expanded, viscous 3D network. At 50% and 75% loadings, the heavy influx of plant electrolytes and organic acids neutralized these repelling charges. This electrical shielding forced the xanthan gum polymer

chains to fold into compact coils, destabilizing the network and causing the sharp drop in viscosity. The brief peak in spreadability at 50% reflects this reduced flow resistance right before the complete matrix collapse at 75%.

The *in vitro* agar well diffusion assay against *Staphylococcus aureus* demonstrated a non-linear relationship between extract concentration and antibacterial efficacy. The 25% *Alpinia galanga* (AG) lotion exhibited strong antistaphylococcal activity, yielding a mean zone of inhibition (22.40 mm) that was statistically comparable to the 2% fusidic acid positive control (21.70 mm). Conversely, the 50% and 75% AG lotions produced significantly reduced zones of inhibition (13.30 mm and 11.70 mm, respectively), making them statistically indistinguishable from the untreated negative control base (12.80 mm).

Because phytochemical evaluations confirm that *A. galanga* rhizome extracts inherently possess potent antibacterial bioactives (Sam et al., 2024), this loss of efficacy at higher concentrations is driven by the physical breakdown of the delivery vehicle rather than diminished plant potency. At 25% loading, the emulsion retained its structural integrity and optimal viscosity (42.80 mPa·s). This physical stability allowed the hydrophilic bioactive compounds (flavonoids, phenols, and alkaloids) to easily partition out of the cream and diffuse freely through the agar matrix.

In contrast, at 50% and 75% formulations, the high extract concentration caused the stabilizing polymeric network to collapse, leading to micro-phase separation and micellar entrapment. The highly polar active constituents became physically locked within localized chemical aggregates. Pharmaceutical studies on natural polymers emphasize that when these formulation networks lose their structural integrity, they create physical barriers that trap active ingredients and severely impede their controlled release (George et al., 2018). This structural lock prevented the antibacterial compounds from diffusing into the surrounding agar, rendering the higher-concentration lotions inactive. Therefore, while *A. galanga* is an effective antibacterial agent, achieving optimal therapeutic success relies heavily on maintaining cosmetic vehicle stability to ensure unhindered drug release.

CONCLUSIONS

The present study demonstrated the formulation and antistaphylococcal evaluation of a topical lotion incorporating the ethanolic rhizome extract of *Alpinia galanga*. Qualitative phytochemical screening confirmed that the crude extract is rich in polar secondary metabolites, specifically flavonoids, alkaloids, phenols, glycosides, and saponins, which serve as the chemical basis for its antimicrobial properties.

Biological evaluation revealed that the 25% *A. galanga* lotion possesses potent in-vitro antistaphylococcal activity. It produced a zone of inhibition statistically comparable to the commercial standard, 2% Fusidic acid cream. This establishes that, at this specific concentration, the oil-in-water emulsion maintains its balance and effectively releases the active plant bioactives to inhibit *Staphylococcus aureus* growth.

However, a formulation threshold was identified at higher concentrations. The 50% and 75% lotions showed lower antibacterial efficacy, performing no better than the untreated lotion base. Physicochemical quality testing revealed that incorporating massive volumes of the acidic, heavily concentrated plant extract caused the viscosity of the lotion to collapse (dropping from 42.80 mPa·s to 9.88 mPa·s). This neutralized the its emulsifying network, physically trapping the active compounds inside the cream and preventing the diffusion into the target area.

Based on these findings, the 25% *A. galanga* lotion is highly recommended as a baseline for natural, plant-based therapies against localized staphylococcal skin infections. To build upon this research, future studies should focus on formulating the extract into non-ionic hydrogels, lipogels, or dense ointments that can physically tolerate higher concentrations of plant electrolytes. An advanced extraction utilizing modern techniques like ultrasound-assisted extraction (UAE) to improve upon the traditional 3.07% maceration yield and conducting advanced chromatographic analysis, such as HPLC or GC-MS, to isolate, quantify, and formally identify the exact bioactive molecules driving the antibacterial mechanism.

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