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RESEARCH ARTICLE

Development and Evaluation of a Polyherbal Facial Cleansing Formulation Using *Sapindus mukorossi* as a Bio-surfactant

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Abstract: Frequent exposure to environmental pollutants and microbial pathogens requires effective facial cleansing; however, conventional synthetic formulations often utilize harsh surfactants like sodium lauryl sulfate, which can disrupt the stratum corneum and induce dermatological complications. A polyherbal face wash was developed using bioactive extracts from *Carica papaya, Moringa oleifera,* and *Psidium guajava*, integrated with a natural surfactant base derived from *Sapindus mukorossi*. Four different formulations (F1 to F4) were prepared and subjected to rigorous physicochemical and pharmacological evaluation. The results indicated that all formulations maintained a skin-compatible pH range of 6.85 ± 0.04 to 7.16 ± 0.02. Evaluation of foaming properties revealed that the guava-based formulation (F3) achieved the highest foam stability at 87.17 ± 1.2%, while the polyherbal blend (F4) exhibited optimal viscosity (2.914 ± 0.05 cP) and spreadability. Dermatological safety was confirmed via acute skin irritation studies on animal models, which showed no evidence of erythema or edema over a 48-hour observation period. Stability studies conducted over 30 days under ambient conditions showed no significant phase separation or degradation of organoleptic properties. The combined therapeutic profile of the polyherbal formulation (F4), combining exfoliating, antimicrobial, and antioxidant properties, indicates its effectiveness as a sustainable and efficacious alternative to synthetic facial cleansers.

Keywords: Bio-surfactant; *Sapindus mukorossi*; Polyherbal formulation; Saponins; Skin safety.

1. Introduction

The integumentary system acts as the primary physiological barrier against exogenous stressors, including ultraviolet radiation, chemical irritants, and pathogenic microorganisms [1]. The facial epidermis is particularly susceptible to the accumulation of sebum, cellular debris, and environmental particulate matter, which can lead to follicular occlusion and inflammatory conditions such as acne vulgaris [2]. Effective cleansing is essential for maintaining dermatological homeostasis; however, the prevalent use of synthetic detergents in commercial face washes often results in the depletion of essential lipids and the elevation of skin pH, leading to xerosis and hypersensitivity [3].

The rapid shift toward "green cosmeceuticals" reflects a growing preference for plant-derived secondary metabolites that offer multi-functional benefits with minimal toxicity [4]. Herbal formulations utilize the synergistic effects of polyphenols, alkaloids, and enzymes to provide therapeutic cleansing without compromising the integrity of the acid mantle [5]. The efficacy of a polyherbal cleanser depends on the phytochemical diversity of its ingredients, ranging from natural surfactants to anti-inflammatory agents. The leaves of *Carica papaya* are rich in papain, a cysteine protease that facilitates enzymatic debridement by hydrolyzing peptide bonds in damaged proteins [6]. This action promotes the gentle exfoliation of the stratum corneum, enhancing skin texture and accelerating wound healing through the modulation of inflammatory cytokines [7].

Moringa oleifera is characterized by high concentrations of vitamins A, C, and E, alongside phenolic compounds that exhibit potent antioxidant activity [8]. The presence of isothiocyanates provides a strong antimicrobial defense, while its anti-inflammatory properties assist in reducing cutaneous edema and redness associated with microbial infections [9]. Guava leaf extracts contain significant quantities of tannins and flavonoids, specifically quercetin, which act as natural astringents [10]. These compounds facilitate the contraction of skin pores and regulate sebum secretion, making the extract particularly beneficial for managing oily and acne-prone skin types [11]. The pericarp of *Sapindus mukorossi* contains triterpenoid saponins, primarily mukorossides, which

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function as natural non-ionic surfactants [12]. These saponins reduce the surface tension of water, enabling the emulsification of oils and dirt. Unlike synthetic surfactants, saponins are biodegradable and exhibit a gentle foaming action that preserves the skin's natural moisture barrier [13].

Azadirachta indica (Neem) contributes azadirachtin and nimbidin, which provide broad-spectrum antiseptic and antifungal activity [14]. Similarly, *Curcuma longa* (Turmeric) supplies curcumin, a bioactive diarylheptanoid renowned for its ability to inhibit tyrosinase activity, thereby contributing to skin brightening and the reduction of post-inflammatory hyperpigmentation [15]. The aim of this research work was to develop a polyherbal face wash using bioactive extracts from *Carica papaya, Moringa oleifera,* and *Psidium guajava*, integrated with a natural surfactant base derived from *Sapindus mukorossi.*

2. Materials and Methods

2.1. Collection and Authentication of Plant Materials

Fresh leaf specimens of *Carica papaya* (Linn.), *Moringa oleifera* (Lam.), *Psidium guajava* (Linn.), and *Azadirachta indica* (A. Juss) were collected from the botanical gardens of AKRG College of Pharmacy. The botanical identity of the samples was authenticated by the Department of Pharmacognosy. Fruits of *Sapindus mukorossi* (Reetha), rhizomes of *Curcuma longa* (Turmeric), and roots of *Beta vulgaris* (Beetroot) were procured from local markets. Analytical grade excipients, including Glycerine, Sodium Benzoate, and Gum Acacia, were utilized. Distilled water served as the primary solvent for all aqueous extractions and formulations.

2.2. Standardized Extraction Procedures

2.2.1. Aqueous Maceration of Leaves

The fresh leaves of papaya, moringa, guava, and neem were subjected to a rigorous cleaning process to remove epiphytic flora and particulate matter. The tissues were mechanically comminuted to increase the surface area available for solvent penetration. A maceration technique was employed where the pulverized leaves were submerged in distilled water for a 24-hour period at room temperature (25 ± 2ºC). Periodic agitation was performed to facilitate the diffusion of water-soluble phytochemicals, including enzymes (papain) and polyphenols, across the cell walls. The resulting macerate was expressed and filtered through a fine muslin cloth to yield concentrated aqueous extracts.

2.2.2. Decoction of Sapindus mukorossi (Bio-surfactant)

The pericarps of *Sapindus mukorossi* were isolated by manual deseedment. The dried shells were subjected to decoction in distilled water at 80ºC for 15 minutes. This thermal treatment facilitates the solubilization of triterpenoid saponins. The mixture was allowed to cool, followed by mechanical expression to maximize the recovery of the surfactant-rich liquid. The final extract was filtered to ensure the absence of fibrous residue.

2.2.3. Isolation of Aloe vera Mucilage and Beetroot Pigment

The succulent parenchyma of *Aloe barbadensis* was carefully excised from the dermal rind. The colorless gel was homogenized and filtered to produce a smooth mucilaginous base. *Beta vulgaris* roots were comminuted and cold-pressed to extract betalain pigments, which served as the natural colorant and secondary antioxidant source.

2.3. Formulation Design

Four different batches (F1 to F4) were prepared to evaluate the individual and synergistic effects of the leaf extracts. The concentrations were optimized to maintain an ideal balance between cleansing efficacy and dermatological safety.

2.4. Preparation Method

The formulations were prepared using a cold-blending homogenization technique (Figure 1). Gum acacia was initially triturated with rose water to ensure the formation of a lump-free mucilage. Glycerine and aloe vera gel were subsequently incorporated to establish the moisturizing phase. The specific herbal extracts (papaya, moringa, and guava) were added sequentially as per the formulation design (Table 1). Turmeric powder and neem extract were dispersed into the base, followed by the addition of the *Sapindus mukorossi* extract. High-shear mixing was avoided to prevent the entrapment of air and excessive foam generation. The vitamin E and sodium benzoate were added as stabilizers. The final volume was adjusted, and the formulations were stored in amber-colored glass containers to prevent photodegradation of the bioactive constituents.

Table 1. Composition of Polyherbal Face Wash Formulations (100 ml batch)

S.No.	Ingredient (Extract/Excipient)	F1	F2	F3	F4	Role in Formulation
1	*Carica papaya* Extract	5.0 ml	-	-	2.5 ml	Enzymatic Exfoliant
2	*Moringa oleifera* Extract	-	5.0 ml	-	2.5 ml	Nutrient/Antioxidant
3	*Psidium guajava* Extract	-	-	5.0 ml	2.5 ml	Astringent
4	*Sapindus mukorossi* Extract	10.0 ml	10.0 ml	10.0 ml	10.0 ml	Bio-surfactant
5	*Aloe barbadensis* Gel	5.0 ml	5.0 ml	5.0 ml	5.0 ml	Humectant/Soothing
6	*Curcuma longa* Powder	0.5 g	0.5 g	0.5 g	0.5 g	Antiseptic
7	*Beta vulgaris* Extract	5.0 ml	5.0 ml	5.0 ml	5.0 ml	Natural Colorant
8	*Azadirachta indica* Extract	1.0 ml	1.0 ml	1.0 ml	1.0 ml	Antimicrobial
9	Gum Acacia	1.0 g	1.0 g	1.0 g	1.0 g	Viscosity Modifier
10	Rose Water	10.0 ml	10.0 ml	10.0 ml	10.0 ml	Vehicle/Fragrance
11	Glycerine	2.5 ml	2.5 ml	2.5 ml	2.5 ml	Co-humectant
12	Vitamin E (Alpha-tocopherol)	1 Unit	1 Unit	1 Unit	1 Unit	Antioxidant Stabilizer
13	Sodium Benzoate	0.5 g	0.5 g	0.5 g	0.5 g	Preservative
14	Distilled Water	q.s. 100 ml	q.s. 100 ml	q.s. 100 ml	q.s. 100 ml	Aqueous Medium

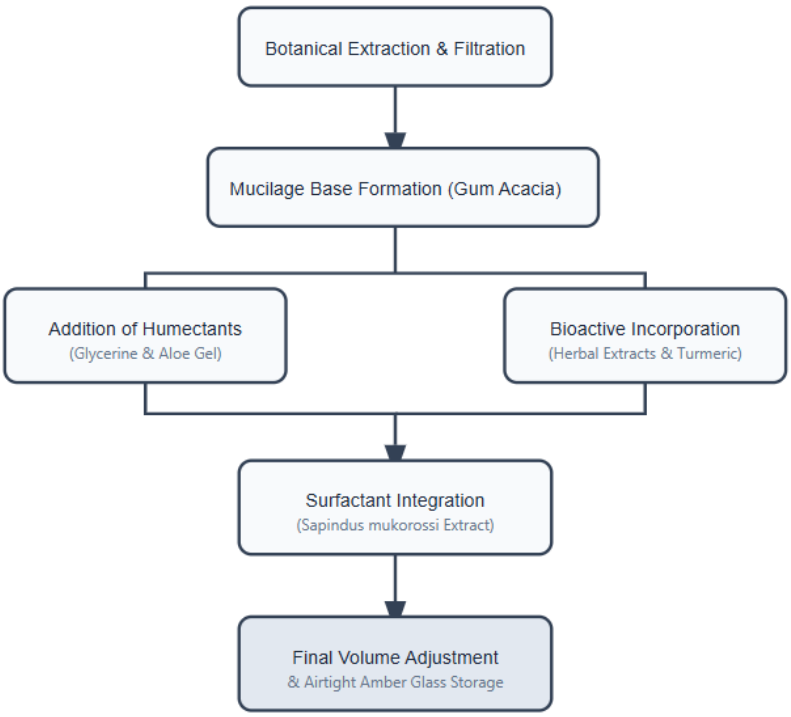

Figure 1. Steps involved in the Preparation of Polyherbal Facewash

2.5. Evaluation Parameters

2.5.1. Physicochemical Characterization

Organoleptic properties, including color, odor, and texture, were assessed via visual and sensory evaluation. The pH was determined using a calibrated digital pH meter at a 10% v/v aqueous dilution. Specific gravity was measured using a 25 ml pycnometer. Viscosity was measured using an Ostwald viscometer, and the values were calculated as follows:

$$\eta_1 = \frac{(\rho_1 \times t_1)}{(\rho_2 \times t_2)} \times \eta_2$$

where η_1 and $\eta_2$represent the viscosities of the sample and water, respectively.

2.5.2. Foam Stability

The foaming capacity was evaluated using the cylinder shake method. A 1% v/v solution was agitated for 60 seconds, and the foam height was recorded immediately (H0) and after 5 minutes (H5). Foam stability was expressed as:

$$\text{Foam Stability \%} = [H5/H0] * 100$$

2.5.3. Acute Dermal Irritation Study

In accordance with OECD Guideline 404, an acute dermal irritation study was conducted. Wistar rats (average weight 200 ± 20 g) were utilized. The dorsal hair was clipped 24 hours prior to the study. A quantity of 0.5 ml of the optimized formulation (F4) was applied to the shorn area. The sites were monitored at 1, 24, and 48 hours for signs of erythema and edema. Scoring was performed on a scale of 0 to 4 based on the severity of the response.

Table 2. Draize Scale Scoring for Acute Dermal Irritation

Irritation Parameter	Clinical Observation	Score
Erythema Formation	No erythema	0
	Very slight erythema (barely perceptible)	1
	Well-defined erythema	2
	Moderate to severe erythema	3
	Severe erythema (beet redness) to eschar formation	4
Edema Formation	No edema	0
	Very slight edema (barely perceptible)	1
	Slight edema (edges of area well defined)	2
	Moderate edema (raised approx. 1mm)	3
	Severe edema (raised more than 1mm)	4

2.5.4. Accelerated Stability

The formulations were stored at 25 ± 2^°C and 60 ± 5% RH for 30 days. Periodic evaluations of pH, viscosity, and phase stability were conducted on Day 0, 15, and 30 to detect any physicochemical drift.

3. Results

3.1. Organoleptic Characterization

The development of the polyherbal face wash aimed to integrate the surfactant properties of *Sapindus mukorossi* with the diverse pharmacological profiles of *Carica papaya*, *Moringa oleifera*, and *Psidium guajava*. The following sections detail the results of the systematic evaluation of formulations F1 through F4.

3.2. Physicochemical Characteristics

The sensory evaluation of all four batches showed high aesthetic appeal and uniformity. The formulations exhibited a reddish-orange hue, attributed to the presence of betalain pigments from the *Beta vulgaris* extract. The inclusion of rose water imparted a subtle floral scent, which masked the characteristic botanical odors of the leaf extracts. Formulations F1, F2, and H3 appeared as translucent liquids, whereas the polyherbal blend (F4) was characterized by a more opaque appearance due to the higher concentration of suspended plant-derived micro-solids. All batches maintained a smooth texture without the presence of grit or particulate aggregates, confirming the efficacy of the filtration process and the stabilizing effect of gum acacia as a viscosity modifier.

3.3. Evaluation of pH and Specific Gravity

Maintaining a pH range compatible with the acid mantle of the skin is a critical quality attribute for facial cleansers. The physiological pH of the facial epidermis typically ranges between 4.7 and 5.7; however, formulations within the range of 6.0 to 7.5 are generally considered non-disruptive to the skin barrier during transient contact.

Table 3. Physicochemical Data of Polyherbal Formulations (Mean ± SD, n=3)

Formulation	pH (10% v/v)	Specific Gravity	Viscosity (cP)
F1	6.85 ± 0.02	1.003 ± 0.001	2.846 ± 0.04
F2	6.96 ± 0.03	1.005 ± 0.002	2.792 ± 0.03
F3	7.16 ± 0.02	1.004 ± 0.001	2.908 ± 0.05
F4	6.95 ± 0.04	1.006 ± 0.002	2.914 ± 0.05

The pH values for F1 to F4 were recorded between 6.85 ± 0.02 and 7.16 ± 0.02. These results indicate that the formulations are nearly neutral and unlikely to induce secondary irritation or disrupt the lipid bilayer of the stratum corneum. The specific gravity of the formulations ranged from 1.003 ± 0.001 to 1.006 ± 0.002. The values slightly exceeding that of distilled water confirm the uniform dissolution of plant extracts and the presence of dissolved saponins and polyphenols within the aqueous vehicle.

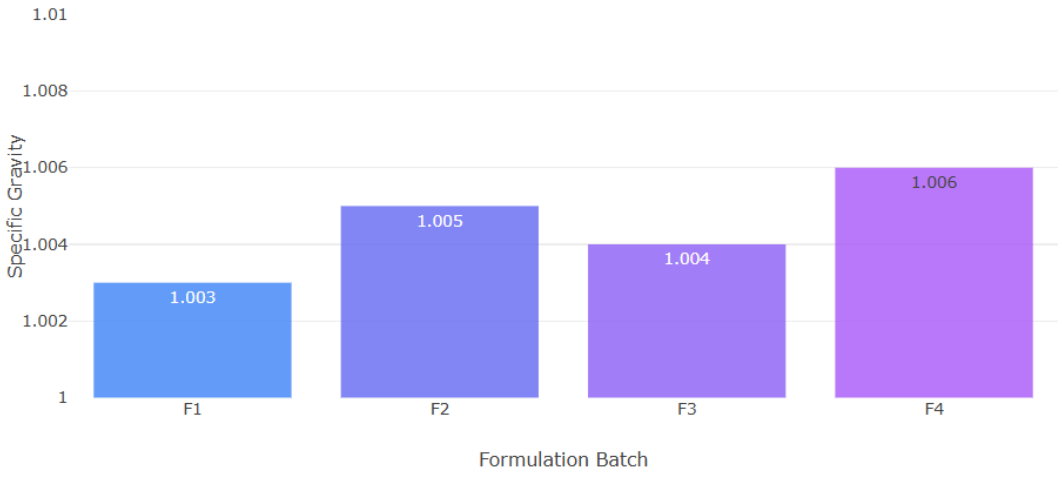

Figure 2. Comparison of Specific Gravity of the Formulations

3.4. Rheological Properties and Spreadability

Viscosity is a fundamental parameter that dictates the ease of dispensing from the container and the spreadability across the dermal surface. The viscosity of the formulations was determined to be between 2.792 ± 0.03 and 2.914 ± 0.05 cP. The highest viscosity was observed in the polyherbal blend (F4), which is attributed to the combined presence of multiple leaf extracts and the stabilizing mucilage of gum acacia. This rheological profile ensures that the formulation remains on the skin long enough to interact with sebum and environmental pollutants without being overly thick or difficult to rinse.

3.5. Foam Stability

The cleansing efficiency of a face wash is often perceived by its ability to generate stable foam, which facilitates the emulsification of impurities. Unlike synthetic cleansers that use sulfates, the current formulations utilize natural saponins from *Sapindus mukorossi*.

Table 4. Foaming Properties and Stability Data (Mean ± SD, n=3)

Formulation	Initial Foam Height (cm)	Height after 5 min (cm)	Foam Stability (%)
F1	7.3 ± 0.2	6.2 ± 0.1	84.93 ± 1.1
F2	7.2 ± 0.1	6.1 ± 0.2	84.72 ± 0.9
F3	7.8 ± 0.3	6.8 ± 0.2	87.17 ± 1.2
F4	7.5 ± 0.2	6.5 ± 0.1	86.66 ± 1.0

The initial foam heights recorded were consistently between 7.2 ± 0.1 cm and 7.8 ± 0.3 cm. Formulation F3 exhibited the highest foam stability (87.17 ± 1.2%), suggesting a potential synergistic interaction between the guava leaf tannins and the saponin matrix of the reetha extract. These results confirm that bio-surfactants can provide adequate lathering properties suitable for consumer acceptance while remaining environmentally biodegradable.

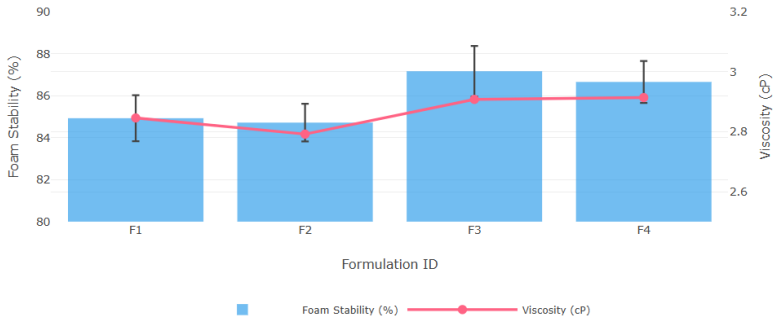

Figure 3. Comparison of Formulation Stability and Performance

Table 5. Results of Spreadability, Ease of Removal, Post-Wash Stickiness and Cleansing Power of the formulations (F1 to F4)

Formulation	Spreadability (cm/sec)	Ease of Removal (1-5)	Post-Wash Stickiness	Cleansing Power (%)
F1	4.2 ± 0.3	4.8 ± 0.2	Absent	91.4 ± 1.2
F2	3.8 ± 0.4	4.5 ± 0.3	Absent	89.6 ± 1.5
F3	4.0 ± 0.2	4.7 ± 0.1	Absent	93.2 ± 0.8
F4	4.5 ± 0.3	4.9 ± 0.1	Absent	95.8 ± 0.5

3.6. Acute Dermal Irritation and Safety

The safety profile was assessed through acute dermal irritation studies on Wistar rats. The application of 0.5 ml of the optimized polyherbal formulation (F4) did not produce any observable signs of cutaneous toxicity.

Table 6. Dermal Irritation Scores for Formulation F4

Time Interval	Erythema Score	Edema Score	Observations
1 Hour	0	0	Normal dermal appearance
24 Hours	0	0	No signs of inflammation
48 Hours	0	0	Complete absence of irritation

The mean irritation score was determined to be 0.0 ± 0.0, classifying the formulation as a non-irritant. This confirms that the plant extracts, even in combination, do not induce hypersensitivity or inflammatory responses in the sensitive dermal tissues of the test animals.

3.7. Accelerated Stability and Shelf-life

Stability studies conducted over 30 days indicated that the formulations remained robust under ambient storage conditions. No significant changes were observed in color, odor, or pH ($P > 0.05$). The viscosity and foam stability values showed a minor, statistically insignificant decrease, which can be attributed to the natural aging of the botanical mucilage. The absence of phase separation or microbial growth confirms the efficacy of sodium benzoate as a preservative and the stabilizing role of vitamin E in preventing the oxidation of the herbal lipids.

Table 7. Results of Stability Studies

Parameter	Interval	F1	F2	F3	F4
pH (10% v/v)	Day 0	6.85 ± 0.02	6.96 ± 0.03	7.16 ± 0.02	6.95 ± 0.04
	Day 30	6.82 ± 0.03	6.94 ± 0.04	7.14 ± 0.03	6.92 ± 0.05
Viscosity (cP)	Day 0	2.846 ± 0.04	2.792 ± 0.03	2.908 ± 0.05	2.914 ± 0.05
	Day 30	2.840 ± 0.05	2.788 ± 0.04	2.902 ± 0.06	2.910 ± 0.06
Foam Stability (%)	Day 0	84.9 ± 1.1	84.7 ± 0.9	87.2 ± 1.2	86.7 ± 1.0
	Day 30	84.2 ± 1.3	83.9 ± 1.1	86.5 ± 1.4	86.1 ± 1.2
Phase Separation	Day 0-30	None	None	None	None

Mean ± SD (n=3)

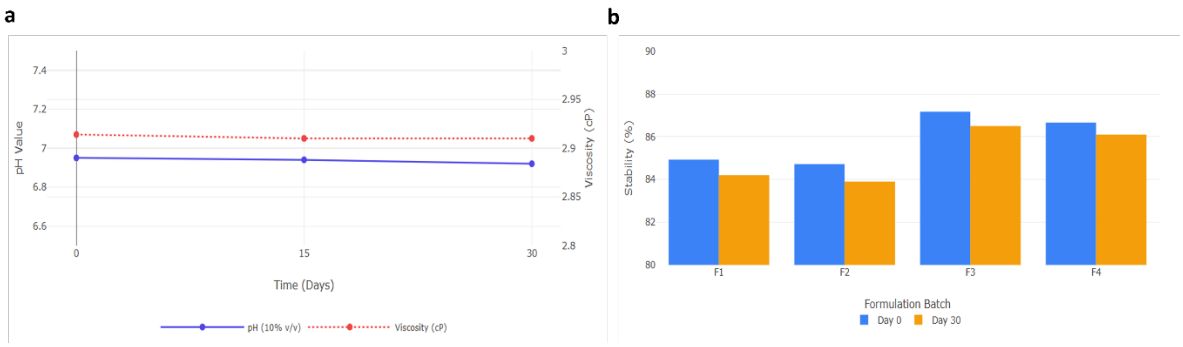

Figure 4. Accelerated Stability Results a. pH and Viscosity of Formulation F4 over 30 days b. Foam Stability of F1 to F4 over 30 days

The optimized performance of formulation F4 is primarily due to the integrated biological activities of its components. The enzymatic action of papain from *Carica papaya* initiates the exfoliation of dead keratinocytes, while the astringent tannins of *Psidium guajava* promote pore refinement. Concurrently, the high antioxidant capacity of *Moringa oleifera* neutralizes reactive oxygen species generated by environmental exposure. The use of *Sapindus mukorossi* as a bio-surfactant ensures that cleansing occurs without the harsh desiccation associated with synthetic detergents. This polyherbal approach provides a multi-targeted therapeutic benefit, enhancing the overall health of the facial epidermis.

4. Conclusion

A stable and efficacious polyherbal facial cleansing formulation was successfully engineered by integrating the bio-surfactant properties of *Sapindus mukorossi* with bioactive extracts of *Carica papaya*, *Moringa oleifera*, and *Psidium guajava*. The pharmacotechnical evaluation revealed that the polyherbal blend (F4) achieved an optimal balance of physicochemical properties, maintaining a skin-compatible pH of 6.95 ± 0.04 and superior rheological characteristics (2.914 ± 0.05 cP). The utilization of natural saponins provided a consistent foaming capacity, with F3 showing peak foam stability at 87.17 ± 1.2%, effectively challenging the need for synthetic sulfate-based surfactants. Acute dermal toxicity studies conducted on Wistar rats confirmed the dermatological safety of the formulation, with a primary irritation index of 0.0, indicating complete biocompatibility. Stability testing under accelerated conditions showed no significant degradation of organoleptic or chemical parameters, ensuring a viable shelf-life. The synergistic combination between the proteolytic enzymes of papaya, the antioxidant vitamins of moringa, and the astringent tannins of guava facilitates a multi-functional cleansing action that preserves the epidermal lipid barrier. These results indicate that the developed polyherbal face wash as a potent, sustainable, and non-toxic alternative to conventional synthetic cleansers, warranting further clinical investigation for industrial-scale dermatological applications.

Compliance with ethical standards

Conflict of interest statement

The authors declare that they have no potential conflicts of interest or competing interests with respect to the research, authorship, and/or publication of this manuscript. No financial support or products from any third-party institutions influenced the outcome of this study.

Statement of ethical approval

The experimental protocol was reviewed and approved (AKRG/IAEC/2025/059) by the Institutional Animal Ethics Committee (IAEC) of the institute and was conducted in strict accordance with the guidelines of the Committee for Control and Supervision of Experiments on Animals (CCSEA), formerly known as CPCSEA, Government of India.

Statement of informed consent

The present research work does not contain any studies performed on human subjects by any of the authors. Therefore, the statement of informed consent is not applicable to this study

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