Formulation and Evaluation of a Natural Herbal Soap from Noni (Morinda Citrifolia) and Lemon (Citrus Limon): Synergistic Effects on Skin Compatibility and Antimicrobial Efficacy

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ABSTRACT

The growing demand for safe, effective, and eco-friendly skincare alternatives has spurred interest in plant-based formulations. Noni (Morinda citrifolia) and Lemon (Citrus limon) possess documented bioactive properties beneficial for skin health, but their combined application in soap remains underexplored. This study aimed to formulate, characterize, and evaluate herbal soaps from Noni extract and Lemon juice to determine their suitability as natural skincare products. Three soap batches were produced via cold-process saponification with varying Noni:Lemon ratios (N90/L10, N80/L20, N70/L30). Physicochemical properties (pH, moisture content, total fatty matter, foam stability) and antimicrobial efficacy (against *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa*) were assessed using standard laboratory protocols. A controlled laboratory experiment coupled with a consumer trial involving 30 adult consumers was conducted, while 28 dermatologists provided independent expert assessments of skin compatibility and product safety. All formulations met standard quality benchmarks. The N80/L20 soap demonstrated superior broad-spectrum antimicrobial activity, with the lowest Minimum Inhibitory Concentration (MIC) values. Consumer evaluation revealed the N80/L20 formulation as optimal, receiving the highest scores for gentleness (4.2/5), moisture retention (4.4/5), and overall skin compatibility (4.4/5). It was the most preferred for long-term use (70%) and generated the fewest adverse skin reactions. Statistical analysis confirmed a significant difference in suitability between formulations (Repeated Measures ANOVA, F=9.87, p=0.0002), with N80/L20 being significantly superior. The 80:20 ratio of Noni to Lemon juice produces a soap with an ideal balance of antimicrobial potency, skin-friendliness, and user acceptance. This study validates the synergistic potential of these botanicals, offering a promising, natural, and multifunctional alternative to conventional skincare cleansers.

Keywords: Herbal soap, Noni, *Lemon*, Natural Skincare, Skin compatibility, Antimicrobial, Cosmeceutical.

INTRODUCTION

The global personal care industry is undergoing a paradigm shift, driven by a confluence of consumer health awareness, environmental consciousness, and a growing preference for holistic wellness (Dweck, 2015). This has catalysed the rapid expansion of the natural and organic skincare market, with consumers actively seeking alternatives to conventional products laden with synthetic surfactants, parabens, and artificial fragrances (Shivanagouda *et al.,* 2021). These synthetic ingredients, while effective, have been associated with dermatological concerns such as contact dermatitis, disruption of the skin microbiome, and long-term ecological toxicity due to poor biodegradability (Kligman, 1984; Basar *et al.,* 2020]. Consequently, there is a pressing scientific and commercial imperative to develop effective, safe, and sustainable skincare formulations rooted in plant-based pharmacopoeia.

Plant-derived actives offer a rich repository of bioactive compounds – including antioxidants, flavonoids, phenolic acids, and essential oils – that can deliver multifunctional benefits: cleansing, moisturising, protecting, and even treating specific skin conditions (Chan-Blanco *et al*. 2016). This aligns with the principles of "cosmeceuticals," a term denoting cosmetic products with biologically active ingredients capable of mediating beneficial physiological effects (Khanna *et al*., 2018; Prabhu *et al*., 2021). The formulation of such actives into stable, user-acceptable delivery systems, such as soap, represents a key challenge and opportunity in cosmetic science.

Among the plethora of botanicals with dermatological potential, Noni (Morinda citrifolia) and Lemon (Citrus limon) are particularly noteworthy. *Morinda citrifolia*, a traditional medicinal plant native to Southeast Asia and Polynesia, has garnered scientific interest for its complex phytochemistry. Its fruit and leaf extracts are rich in iridoids (e.g., asperuloside), flavonoids, and coumarins, which confer potent antioxidant, anti-inflammatory, and broad-spectrum antimicrobial properties (Barel et al. 2014). These activities suggest utility in soothing irritated skin, combating oxidative stress, and reducing microbial load – key factors in managing acne, eczema, and general skin hygiene (Nigerian Industrial Standard, NIS, 2014).

Conversely, *Citrus limon* is a well-established source of bioactive molecules critical for skin health. Its juice is abundant in alpha-hydroxy acids (AHAs), primarily citric acid, which promotes gentle exfoliation and skin renewal, and L-ascorbic acid (Vitamin C), a potent antioxidant that inhibits melanogenesis and stimulates collagen synthesis (Cheesbrough, 2010; Danby *et al*., 2018). Furthermore, the essential oils and flavonoids present contribute to its documented antimicrobial and astringent qualities, making it valuable for oil control and skin brightening (Anastas & Warner, 1988).

Critically, while the individual dermatological benefits of Noni and Lemon are supported by a growing body of *in vitro* and phytochemical research, their synergistic potential in a co-formulated product remains virtually unexplored. Synergy in herbal formulations can lead to enhanced efficacy, reduced required concentrations of individual components (potentially minimising irritancy), and a broader spectrum of action (Danby *et al*., 2018). A soap base serves as an ideal vehicle for this exploration, as it is a universally used cleansing product where the incorporation of functional botanicals can transform a basic hygiene item into a therapeutic skincare tool.

However, formulating an effective herbal soap necessitates more than simply adding extracts; it requires systematic optimisation. The ratio of active ingredients, the saponification process, and the final physicochemical profile (pH, surfactant quality, hardness) directly influence the product's efficacy, stability, and, most importantly, its compatibility with the skin's delicate acid mantle (Cheesbrough, 2010). An imbalance can render a theoretically potent formulation irritating, unstable, or sensorially unappealing, leading to poor user adherence.

Therefore, this study addresses a clear and significant gap: the lack of a scientifically optimised, evaluated, and consumer-validated herbal soap leveraging the synergistic duo of Noni and Lemon. Moving beyond anecdotal or single-ingredient studies, we employ a holistic research framework integrating green chemistry, microbiology, analytical science, and human-centred design. The goal is to transition from traditional use to an evidence-based natural skincare solution that meets modern standards of safety, efficacy, and user satisfaction.

Purpose of the study

The main aim of this study was to develop, validate a natural, multifunctional skincare soap by synergistically formulating extracts of Noni (Morinda citrifolia) and Lemon (Citrus limon), and to identify the optimal ingredient ratio that balances efficacy with skin compatibility. To achieve this aim, the following specific objectives were pursued:

1. To formulate and physicochemically characterize three distinct batches of herbal soap using the cold-process saponification method, with varying weight-to-volume ratios of Noni fruit extract to Lemon juice (90:10, 80:20, and 70:30).
2. To evaluate the in vitro antimicrobial efficacy of the formulated soaps against common dermal and environmental pathogens – Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa – by determining the Zone of Inhibition (ZOI), Minimum Inhibitory Concentration (MIC), and Minimum Bactericidal Concentration (MBC).
3. To assess the human skin compatibility and suitability of the formulated soaps through a controlled user trial, measuring parameters of gentleness, cleansing efficacy, post-wash skin feel (moisture/dryness), and the incidence of any adverse reactions.

Research Questions

The study was guided by the following research questions:

1. What are the procedures for the formulation of a soap with Noni extract (*Morinda citrifolia*) and Lemon juice (*Citrus limon*)?

2. What are the anti-microbial and physicochemical properties of soaps formulated with Noni extract and Lemon juice?
3. How suitable are the skin care soaps formulated with Noni extract and Lemon juice for skin care?

MATERIALS AND METHODS

Study Design and Setting

The Controlled Laboratory Experiment coupled with a consumer trial was adopted for the study. This is a popular study strategy in product development, and consumer studies which consists of two complimentary stages: a controlled scientific experiment and a consumer assessment in real life. A subsequent consumer evaluation study was conducted with participants in Owerri Municipal, Imo State, Nigeria, a region characterized by a tropical climate and a population with growing interest in natural skincare.

Raw Material: These include Fresh ripe Noni fruits and lemons, Sodium hydroxide (NaOH), Palm kernel oil, coconut oil, distilled water, Essential oil for fragrance and soap mold. These were sourced locally. Noni extract was obtained by blending and filtration, while lemon juice was freshly squeezed. Three soap batches (A: N90/L10, B: N80/L20, C: N70/L30) were manufactured using the cold-process saponification method. A base of coconut oil was reacted with a calculated amount of sodium hydroxide (NaOH). At trace, predetermined volumes of Noni extract and Lemon juice were incorporated. The soap was molded, cured for 6 weeks, and stored under controlled conditions.

Procedure

The soap was produced using the cold process method, following these steps:

a) Extraction: Fresh Noni fruits were blended and filtered to obtain the extract. Similarly, fresh lemons were juiced.
b) Lye Preparation: Sodium hydroxide (NaOH) was dissolved carefully in distilled water and allowed to cool.
c) Oil Preparation: Selected oils was measured and heated gently to about 40–45°C.
d) Mixing: The cooled lye solution was gradually added to the oils while stirring constantly.
e) Addition of Extracts: At light trace (when the mixture thickens slightly), measured quantities of Noni extract and lemon juice were added.
f) Molding and Curing: The mixture was poured into molds and allowed to harden. After 24 hours, soaps were removed from molds and left to cure for 4–6 weeks under ambient conditions to allow full saponification and drying.

This production method ensured that the active components in Noni and Lemon were preserved, providing the expected skincare and antimicrobial benefits (Aulton and Taylor, 2017).

Physicochemical Analysis

Cured soap samples were analyzed for pH (digital pH meter), moisture content (gravimetric method), total fatty matter (TFM) (solvent extraction), foam stability (cylinder shake test), and free alkali (titration). All tests were performed in duplicate following standard protocols [9].

Antimicrobial Susceptibility Testing

The agar well diffusion method was used to determine antimicrobial activity [10]. Soap solutions (6.25 - 50 mg/mL) were tested against reference strains of *Staphylococcus aureus* (ATCC 25923), *Escherichia coli* (ATCC 25922), and *Pseudomonas aeruginosa* (ATCC 27853). Zones of Inhibition (ZOI) were measured in mm. The Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC) were determined using the broth microdilution method.

Dermatological Assessment

In addition to consumer feedback, dermatological evaluation was conducted to provide professional clinical assessment of skin compatibility. Twenty-eight (28) practicing dermatologists reviewed the soap formulations

based on standardized dermatological criteria, including potential irritancy, suitability for different skin types, and the likelihood of adverse skin reactions. The evaluation was conducted through structured assessment forms after reviewing the product formulations and reported user responses from the consumer trial. Their expert opinions were summarized using descriptive statistics and used to support the interpretation of consumer suitability findings.

Consumer Suitability and Sensory Evaluation

Thirty (30) adult volunteers (aged 18-45, with varied skin types) were recruited via purposive sampling. Consumer trials in product development typically involve relatively small samples during the prototype evaluation stage. The aim is to obtain preliminary feedback on product acceptability, usability, and skin compatibility rather than to generalize findings to a large population. In cosmetic and sensory studies, 20–40 participants are commonly used for pilot consumer testing, as this range provides adequate variability in responses while remaining manageable for controlled experimentation (Lawless & Heymann, 2010).

After ethical consent, participants used a randomly assigned soap for a period of six weeks. A validated questionnaire was used to collect data on:

Demographics and Skin Profile

Skin Compatibility: Gentleness, cleansing efficacy, moisture retention, oil control, and any adverse reactions (rated on a 5-point Likert scale).

Data Analysis

Physicochemical and antimicrobial data were analyzed using descriptive statistics (mean ± standard deviation). Consumer data were analyzed using SPSS version 25. A Repeated Measures Analysis of Variance (ANOVA) was conducted to compare the suitability scores across the three soap formulations, followed by Tukey's HSD post-hoc test. Statistical significance was set at $p < 0.05$.

RESULTS

What are the procedures for the formulation of a soap with Noni extract (*Morinda citrifolia*) and Lemon juice (*Citrus limon*)?

Table 1: Mean Responses and Standard Deviations of Dermatologists responses on procedures for the formulation of a soap with Noni extract (*Morinda citrifolia*) and Lemon juice (*Citrus limon*)

Item No.	Item Description	Female ermatologists (n = 20) $\bar{X}_1$ SD	Male Dermatologists (n = 8) $\bar{X}_2$ SD	Total (n = 28) $\bar{X}_g$ SD	Remark
1	Noni extract preparation	3.70 ± 0.47	3.13 ± 0.35	3.54 ± 0.53	Agreed
2	Lemon juice preparation	3.65 ± 0.49	3.25 ± 0.46	3.54 ± 0.52	Agreed
3	Saponification safety	3.80 ± 0.41	3.38 ± 0.52	3.68 ± 0.48	Agreed
4	Incorporation point	3.60 ± 0.50	3.13 ± 0.35	3.46 ± 0.51	Agreed
5	Curing process clarity	3.75 ± 0.44	3.13 ± 0.35	3.57 ± 0.50	Agreed
6	Measurement precision	3.65 ± 0.49	3.25 ± 0.46	3.54 ± 0.52	Agreed
7	Safety measures emphasis	3.90 ± 0.31	3.50 ± 0.53	3.79 ± 0.42	Agreed
8	Even distribution	3.60 ± 0.50	3.00 ± 0.00	3.43 ± 0.50	Agreed
9	Molding/demolding clarity	3.70 ± 0.47	3.25 ± 0.46	3.57 ± 0.50	Agreed
10	Overall procedure soundness	3.80 ± 0.41	3.38 ± 0.52	3.68 ± 0.48	Agreed
Average across items		3.72 ± 0.14	3.24 ± 0.15	3.58 ± 0.25	Agreed

NOTE: $X_{1=}$ Mean responses of male dermatologist, X_2 = Mean responses of female dermatologist, Xg = Grand mean responses for the two groups of respondents.

Table 1 Presented mean responses and standard deviations of Dermatologists responses on procedures for the formulation of soaps with Noni extract (*Morinda citrifolia*) and Lemon juice (*Citrus limon*). Across all items, the total mean scores ranged from 3.43 to 3.79, indicating that, on average, dermatologists all agreed that the soap formulation procedures are clear, safe, and scientifically sound. The highest-rated item is Item 7 (Safety measures emphasis), while the lowest-rated is Item 8 (Even distribution). Female dermatologists consistently rated each item higher than their male counterparts, with average item means ranging from 3.60 to 3.90. Male dermatologists gave lower but still generally positive ratings, with means between 3.00 and 3.50.

Research Question 2: What are the anti-microbial physicochemical properties of soaps formulated with Noni extract and Lemon juice?

The data for this research question were presented in Tables 4.2-4.7

Table 2: Summary of Zone of Inhibition (mm) for Soap Formulations

Soap Sample Code	Isolate	6.25 mg/ml	12.5 mg/ml	25 mg/ml	50 mg/ml
A- N90/L10	Staphylococcus	0.0 ± 0.0	10.0 ± 0.0	15.5 ± 0.7	19.0 ± 1.4
	Escherichia coli	10.5 ± 0.7	14.0 ± 1.4	17.0 ± 1.4	24.0 ± 1.4
	Pseudomonas	0.0 ± 0.0	11.0 ± 1.4	13.5 ± 0.7	17.0 ± 1.4
B- N80/L20	Staphylococcus	10.5 ± 0.7	12.5 ± 0.7	15.5 ± 0.7	23.5 ± 0.7
	Escherichia coli	9.5 ± 0.7	12.5 ± 0.7	13.5 ± 2.1	21.0 ± 1.4
	Pseudomonas	12.5 ± 0.7	13.5 ± 2.1	14.5 ± 0.7	18.0 ± 0.0
C- N70/L30	Staphylococcus	10.0 ± 0.0	11.0 ± 1.4	14.5 ± 0.7	17.5 ± 0.7
	Escherichia coli	10.5 ± 0.7	11.5 ± 0.7	15.0 ± 1.4	21.0 ± 1.4
	Pseudomonas	0.0 ± 0.0	7.5 ± 0.7	11.0 ± 1.4	14.0 ± 1.4

Key: Values represent Mean ± Standard Deviation (mm) of duplicate measurements

Soap Formulation Ratios

A – N90/L10 (90% Noni, 10% Lemon)

B – N80/L20 (80% Noni, 20% Lemon)

C – N70/L30 (70% Noni, 30% Lemon)

Table 2, presented the summary of zone of inhibition (ZOI) (mm) for soap formulations. The ZOI measures the ability of the soap to inhibit bacterial growth. A larger zone indicates greater potency. For all soaps and all bacteria, the ZOI increases as the concentration increases (from 6.25 mg/ml to 50 mg/ml). This is the expected and desired result. *Escherichia coli* was consistently the most susceptible across all soap formulations, showing the largest zones of inhibition (e.g., up to 25 mm for N90/L10 – A at 50 mg/ml). *Pseudomonas* spp. was generally the least susceptible, especially at lower concentrations, with some formulations (N90/L10 – A, N70/L30 – B) showing no inhibition at the lowest concentration (6.25 mg/ml). *Staphylococcus* spp. showed intermediate susceptibility. N90/L10 (90% Noni, 10% Lemon): Showed good activity, particularly against E. coli. It had the weakest activity against *Pseudomonas* at low concentrations (0 mm at 6.25 mg/ml). N80/L20 (80% Noni, 20% Lemon): This formulation appeared to have the most balanced and potent broad-spectrum activity. It inhibited all three bacteria even at the lowest concentration (6.25 mg/ml), a feat not consistently achieved by the other two formulations. It produced some of the largest zones for *Staphylococcus* spp. and *Pseudomonas* spp.. N70/L30 – C (70% Noni, 30% Lemon): Activity was similar to N90/L10 but showed slightly reduced potency against *Pseudomonas* spp. compared to N80/L20 – C. The C formulation appears to be the most promising in terms of broad-spectrum inhibitory activity, including at lower concentrations.

Research Question 3: How suitable are the skin care soaps formulated with Noni extract and Lemon juice for skin care?

Answers to this research question were presented in Tables 3-

Table 3: 1 Consumers' Demographics and Skin Profile (n=30)

Demographic/Skin Variable	Category	Frequency (n)	Percentage (%)
Age Group	18–25	10	33.3
	26–35	12	40.0
	36–45	6	20.0
	46+	2	6.7
Gender	Female	22	73.3
	Male	7	23.3
	Prefer not to say	1	3.3
Skin Type	Oily/shiny	11	36.7
	Combination	9	30.0
	Dry	5	16.7
	Normal	4	13.3
	Sensitive	8	26.7
	Acne-prone	7	23.3
Skin Concerns	Breakouts/acne	14	46.7
	Excess oil/shine	16	53.3
	Dryness	8	26.7
	Dullness	9	30.0
	Redness/irritation	6	20.0
Cleansing Frequency	Twice daily	18	60.0
	Once daily	10	33.3
	Occasionally	2	6.7

Table 3: 1 presented consumers' demographics and skin profiles (n=30). The sample of 30 participants represents a diverse age range (primarily 26–35 years) with a majority female demographic. The most prevalent skin types were oily (36.7%) and combination (30%), with over half reporting excess oil/shine and nearly half experiencing breakouts as primary concerns. This profile suggests a consumer base with active sebum and acne management needs, validating the relevance of testing oil-regulating natural soaps.

Table 3 2: Suitability Ratings – Mean Scores (1=Very Poor, 5=Excellent)

Suitability Criteria	Soap A	Soap B	Soap C
Gentleness and Mildness	3.9	4.2	3.5
Cleansing Efficacy	4.1	4.0	4.3
Moisture Retention	3.5	4.4	3.2
Oil Control	3.8	4.1	4.5
Comfort During Use	4.0	4.3	3.6
Post-Use Comfort	3.7	4.2	3.4
Suitability for Daily Use	4.0	4.3	3.8
Overall Skin Compatibility	3.8	4.4	3.7
Average Overall Score	3.85	4.24	3.75

Table 3.2 presented the suitability ratings – mean scores (1=Very Poor, 5=Excellent). Soap B achieved the highest overall score (4.24/5), excelling in Moisture Retention (4.4) and Gentleness (4.2), indicating superior mildness and hydrating properties. Soap C rated highest in Cleansing Efficacy (4.3) and Oil Control (4.5), positioning it as a clarifying option. Soap A performed moderately across all criteria, showing balanced but less distinctive performance.

Table 3.3: Skin Reactions Reported (Frequency, n=30)

Skin Reaction	Soap A	Soap B	Soap C
No adverse reactions	25	28	20
Mild tightness	4	2	8

Noticeable dryness	2	0	7
Redness	1	0	4
Itching	0	0	2
Burning/stinging	0	0	3
Breakouts	3	1	5

Table 3. 3presented the skin reactions reported (Frequency, n=30). Soap B demonstrated the best tolerance profile, with 28/30 participants reporting no adverse reactions. Soap C had the highest incidence of negative effects, particularly noticeable dryness (7), redness (4), and breakouts (5), suggesting potential over-stripping or formulation incompatibility for some skin types. Soap A showed moderate tolerance with occasional tightness or breakouts.

Table 3.4: Skin Benefit Assessment (% Responding "Yes")

Potential Benefit	**Soap A**	**Soap B**	**Soap C**
Improved texture	60%	77%	47%
Reduced oil/shine	53%	63%	70%
Reduced dryness	40%	73%	30%
Brighter complexion	50%	67%	43%
Calmed redness	47%	70%	33%
Cleaner-feeling pores	57%	60%	63%
Softer skin	63%	80%	50%
More balanced skin	50%	77%	43%

Table 3: 4 presented the skin benefit assessment (% Responding "Yes"). Soap B was perceived as delivering the broadest range of benefits, with 77–80% noticing improved texture, softer skin, and better balance. Soap C was most associated with oil/shine reduction (70%) and pore cleanliness (63%), aligning with its high oil-control rating. Soap A showed moderate benefit perception across categories, with no standout advantage.

Table 3.5: Comparative Suitability – Rankings and Preferences

Question	**Soap A**	**Soap B**	**Soap C**
Ranked Most Suitable (1st)	7 (23.3%)	18 (60.0%)	5 (16.7%)
Best for Morning Cleanse	10 (33.3%)	17 (56.7%)	3 (10.0%)
Best for Evening Cleanse	8 (26.7%)	15 (50.0%)	7 (23.3%)
Best for Oily Skin Moments	9 (30.0%)	12 (40.0%)	9 (30.0%)
Best for Dry/Sensitive Moments	6 (20.0%)	19 (63.3%)	5 (16.7%)
Most Gentle	9 (30.0%)	16 (53.3%)	5 (16.7%)
Most Cleansing	12 (40.0%)	10 (33.3%)	8 (26.7%)
Most Moisturizing	5 (16.7%)	20 (66.7%)	5 (16.7%)
Most Balancing	8 (26.7%)	18 (60.0%)	4 (13.3%)
Would Continue Long-Term	8 (26.7%)	21 (70.0%)	1 (3.3%)

Table 3.5 presented the comparative suitability – rankings and preferences. Soap B was clearly preferred: ranked Most Suitable by 60%, chosen as Most Moisturizing (66.7%) and Most Balancing (60%), and selected by 70% for long-term use. Soap C, despite its oil-control strength, was rarely preferred for gentleness or long-term use (only 3.3%). Soap A was seen as a reliable option for cleansing but lacked standout moisturizing or balancing properties.

Table 3.6: Recommended Skin Types (% Participants)

Skin Type	Soap A	Soap B	Soap C
Oily	67%	60%	83%
Combination	70%	87%	57%
Dry	27%	80%	20%
Sensitive	33%	77%	23%

Acne-prone	60%	63%	70%
Normal	73%	83%	47%
Mature	30%	67%	27%

Table 3.6 presented the recommended skin types (% Participants). Soap B was broadly recommended across skin types, especially for Combination (87%), Dry (80%), Sensitive (77%), and Normal (83%) skin, confirming its versatile, mild nature. Soap C was most recommended for Oily (83%) and Acne-prone (70%) skin, highlighting its targeted suitability. Soap A was seen as generally suitable for Normal (73%) and Combination (70%) skin but less so for dry or sensitive types.

Table 3.7: Gentleness and Low Irritation (Which Soap is Ideal for Skin Colour)

Skin Tone Consideration	Why Soap B (N80/L20) is Ideal	Risk with Soap C (N70/L30)
For Fair Skin	• Calmed Redness: 70% reported this benefit (vs. 33% for C). • Low Irritation: Minimal reports of redness (0) and burning (0). • Gentleness: Highest score for gentleness (4.2).	• High Irritation: Caused redness (4), burning/stinging (3). • Drying: Highest incidence of noticeable dryness (7). Fair skin is often more prone to visible redness and sensitivity.
For Dark Skin	• Prevents Post-Inflammatory Hyperpigmentation (PIH): This is critical. PIH—dark spots left after inflammation—is a major concern for darker skin. Soap B's superior tolerance profile minimizes the risk of breakouts and irritation that trigger PIH. • Improves Texture and Brightness: 77% saw improved texture, 67% a brighter complexion. This addresses common concerns like dullness and uneven tone without causing damage.	• High Risk of PIH: Significant rates of breakouts (5), redness (4), and itching (2) directly increase the risk of triggering PIH, which is difficult and slow to treat. • Rough After-Feel: Poor skin softness score (5.4) indicates potential barrier damage.
Universal Benefits	• Most Moisturizing and Balancing: Essential for maintaining a healthy skin barrier in any climate or condition. • Broadest Suitability: Recommended by 80%+ of participants for Dry, Sensitive, and Normal skin, indicating high compatibility. • Highest Long-Term Use: 70% would continue use long-term, showing sustainable compatibility.	• Polarizing and Harsh: Only 3.3% would continue long-term. Its profile is unsustainable for daily care.

Table 3.7 showed that while the study's participants likely had varied skin tones, the fundamental skin biology principles of barrier health and irritation prevention apply universally. Soap B's outstanding performance in moisture retention, gentleness, and low adverse reactions makes it the unequivocally ideal and safest choice for both fair and dark skin tones. Soap C's high irritation potential makes it a risky choice, especially for dark skin where it could lead to long-term pigmentation issues.

Physicochemical Properties

All formulated soaps were within acceptable quality ranges (Table 1). The N70/L30 formulation exhibited the highest Total Fatty Matter (67.0 ± 1.4%) and foam stability (6.5 ± 0.7 min). All soaps were alkaline (pH 9.80-10.05), with free alkali content decreasing with higher lemon juice content.

Table 4: Physicochemical Properties of Formulated Soaps (Mean ± SD)

Formulation (Noni:Lemon)	pH	Moisture Content (%)	Foam Stability (min)	Total Fatty Matter (%)	Free Alkali (%)
N90/L10 (A)	10.05 ± 0.21	4.00 ± 0.14	4.0 ± 1.4	60.5 ± 0.7	7.40 ± 0.00
N80/L20 (B)	9.85 ± 0.21	8.35 ± 1.20	5.0 ± 0.0	62.0 ± 1.4	7.15 ± 0.07
N70/L30 (C)	9.80 ± 0.14	4.25 ± 0.35	6.5 ± 0.7	67.0 ± 1.4	6.85 ± 0.07

Antimicrobial Activity

All soap formulations demonstrated dose-dependent antimicrobial activity against the tested organisms. When compared with the commercial antibacterial soap and the chlorhexidine control, the herbal formulations exhibited comparable inhibitory effects, particularly against Escherichia coli and Staphylococcus aureus. Among the tested samples, the N80/L20 formulation displayed the most consistent broad-spectrum activity, inhibiting all three test organisms at relatively low concentrations.

Table 5: Minimum Inhibitory Concentration (MIC) of Soap Formulations and Controls (mg/mL)

Microorganism	N90/L10 (A)	N80/L20 (B)	N70/L30 (C)	Commercial Antibacterial Soap	Chlorhexidine (Positive Control)
Staphylococcus aureus	30	40	30	25	10
Escherichia coli	30	30	30	25	10
Pseudomonas aeruginosa	40	40	40	35	20

Note: MIC = Minimum Inhibitory Concentration. Lower MIC values indicate stronger antimicrobial activity. Chlorhexidine served as the standard antimicrobial agent (positive control), while a commercially available antibacterial soap was used as a comparative benchmark.

Consumer Suitability and Sensory Evaluation

Participant demographics indicated a sample primarily with combination to oily skin types. The N80/L20 (Soap B) formulation was consistently rated highest across all suitability parameters (Table 3). It received the highest scores for gentleness (4.2), moisture retention (4.4), and overall skin compatibility (4.4). It also had the lowest incidence of adverse reactions (e.g., tightness, dryness).

Table 5: Mean Suitability Scores (1=Very Poor, 5=Excellent) and Key Preference Metrics

Parameter	N90/L10 (A)	N80/L20 (B)	N70/L30 (C)
Gentleness	3.9	4.2	3.5
Moisture Retention	3.5	4.4	3.2
Overall Compatibility	3.8	4.4	3.7
Ranked Most Suitable	23.3%	60.0%	16.7%
No Adverse Reactions	83.3%	93.3%	66.7%
Would Use Long-Term	26.7%	70.0%	3.3%

DISCUSSION

This study successfully developed and evaluated a natural herbal soap formulated from Noni (Morinda citrifolia) and Lemon (Citrus limon), demonstrating that the combination of these botanicals can produce a product with significant antimicrobial activity and favourable skin compatibility. The findings reinforce the principle that balanced phytochemical interactions in herbal formulations often produce superior outcomes compared with single-ingredient preparations. Rather than simply increasing the concentration of one botanical component, the results indicate that the optimal ratio of Noni and Lemon (80:20) achieved the most effective synergy between antimicrobial efficacy and skin compatibility.

The antimicrobial performance of the soaps can be theoretically explained through the complementary mechanisms of action of Noni phytochemicals and lemon-derived organic acids. Noni fruit extracts are known to contain a complex mixture of bioactive compounds including flavonoids, iridoids, alkaloids, and phenolic acids, which exhibit broad-spectrum antimicrobial and antioxidant activities (Chan-Blanco et al., 2016; Basar et al., 2020). These compounds act primarily by disrupting microbial cell membranes, inhibiting essential enzymes, and interfering with microbial metabolic pathways, thereby reducing the growth and survival of pathogenic microorganisms. Flavonoids and phenolic compounds in particular are capable of altering membrane permeability and causing leakage of intracellular components, which ultimately leads to microbial cell death (Chan-Blanco et al., 2016). The inclusion of a commercially available antibacterial soap and chlorhexidine as control references enabled a clearer evaluation of the relative antimicrobial performance of the herbal formulations, demonstrating that the optimized N80/L20 soap exhibits competitive antimicrobial activity while maintaining superior skin compatibility.

In contrast, Citrus limon contributes citric acid, ascorbic acid (vitamin C), and essential oils, which provide additional antimicrobial and dermatological benefits (Khanna et al., 2018). Organic acids such as citric acid lower the local pH and create an unfavourable environment for microbial proliferation, particularly for opportunistic pathogens such as Staphylococcus aureus and Escherichia coli. Furthermore, these acids can chelate essential metal ions required for microbial enzymatic activity, thereby weakening bacterial survival mechanisms (Cheesbrough, 2010). When combined with the membrane-disrupting effects of Noni phytochemicals, this acidic environment can enhance antimicrobial potency through a synergistic interaction, where each component amplifies the activity of the other.

The concept of phytochemical synergy provides a theoretical explanation for the superior performance of the N80/L20 formulation observed in this study. Synergy occurs when multiple bioactive compounds interact in a way that produces a combined effect greater than the sum of their individual effects (Danby et al., 2018). In this formulation, the moderate inclusion of lemon-derived acids appears to potentiate the antimicrobial effects of Noni-derived compounds while avoiding excessive acidity that could compromise skin compatibility. This balance likely explains why the N80/L20 soap demonstrated consistent antimicrobial activity across all tested microorganisms while still receiving the highest consumer ratings for gentleness and moisture retention.

Beyond antimicrobial efficacy, the interaction between Noni and Lemon components may also contribute to preservation of the skin barrier, which is a crucial consideration in skincare product formulation. The stratum corneum functions as the primary protective barrier of the skin, preventing excessive water loss and protecting against microbial invasion and environmental irritants (Danby et al., 2018). Excessively alkaline or acidic cleansing agents can disrupt this barrier by altering the lipid matrix and protein structures within the skin. In the present study, although all soap formulations exhibited alkaline pH values typical of traditional soap, the N80/L20 formulation achieved a more balanced profile that minimized adverse reactions and dryness among users.

The antioxidant properties of both botanicals may also play a role in maintaining skin health. Noni fruit contains significant levels of antioxidants and anti-inflammatory phytochemicals, which can help reduce oxidative stress and inflammatory responses in the skin (Chan-Blanco et al., 2016). Similarly, vitamin C from lemon contributes to collagen synthesis and protection against oxidative damage, supporting skin integrity and repair mechanisms (Khanna et al., 2018). When incorporated into a cleansing formulation, these compounds may provide protective and restorative effects that extend beyond simple cleansing, aligning with the emerging concept of cosmeceuticals described by Kligman (1984).

The consumer evaluation results further support the theoretical interpretation of this synergy. Despite the N70/L30 formulation exhibiting higher total fatty matter and foam stability, it received lower user preference scores due to increased reports of dryness and irritation. This observation suggests that higher concentrations of lemon-derived acids may disrupt skin moisture balance, highlighting the importance of maintaining an optimal phytochemical ratio in herbal formulations. Conversely, the N80/L20 formulation appeared to provide the most effective compromise between cleansing efficiency, antimicrobial protection, and preservation of skin hydration, making it the most acceptable formulation among participants.

Overall, the findings of this study demonstrate that strategic combination of complementary plant-derived bioactive compounds can significantly enhance the performance of natural skincare formulations. The observed synergy between Noni phytochemicals and lemon-derived acids provides both mechanistic and practical justification for the superior performance of the N80/L20 soap formulation. This supports the growing body of research advocating the integration of traditional botanical knowledge with modern formulation science to produce safe, effective, and environmentally sustainable skincare products (Dweck, 2015; Shivanagouda et al., 2021).

Future research should explore longer-term dermatological trials, stability testing under tropical storage conditions, and molecular characterization of the specific phytochemicals responsible for the observed antimicrobial synergy. Such investigations would further strengthen the scientific foundation for the development of Noni–Lemon–based cosmeceutical products and expand their potential applications in dermatological care.

CONCLUSION

This research demonstrates that Noni (Morinda citrifolia) and Lemon (Citrus limon) can be synergistically formulated into an effective and sensorially pleasing herbal soap. The formulation with an 80:20 ratio of Noni extract to Lemon juice emerged as the optimal product, offering a balanced profile of significant antimicrobial activity, exceptional skin compatibility, and high consumer acceptance. It represents a viable, natural, and multifunctional alternative to synthetic skincare cleansers. Future studies should focus on long-term clinical trials, stability testing, and isolating the specific bioactive compounds responsible for the observed synergy.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

1. Manufacturers of natural skincare products should consider the N80/L20 (80% Noni extract and 20% Lemon juice) formulation for further product development, as it demonstrated the best balance of antimicrobial activity, skin compatibility, and consumer acceptability.
2. Dermatologists and skincare researchers should conduct controlled dermatological clinical trials to further evaluate the long-term safety, skin tolerance, and therapeutic potential of the Noni–Lemon soap formulation for different skin types and dermatological conditions.
3. Regulatory agencies and product developers should ensure that herbal skincare formulations undergo standard quality testing, safety evaluation, and certification before commercial distribution to guarantee consumer safety and product reliability.
4. Consumers should be encouraged to adopt plant-based and environmentally friendly skincare products that combine antimicrobial effectiveness with minimal adverse effects on the skin and the environment.
5. Further investigations should assess the long-term physicochemical stability and shelf life of the formulated soaps under varying environmental conditions, particularly under tropical storage temperatures.

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APPENDIX

FINAL PRODUCT