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Research Article

Preparation and Evaluation of Herbal Hand Sanitizer

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This research provides valuable insights into the use of medicinal plants for hand hygiene, a critical preventive measure in the control of infectious diseases. The global COVID-19 pandemic underscored the necessity of effective sanitization products, but it also exposed the limitations of alcohol-based sanitizers. The development of a natural, plant-based hand sanitizer addresses multiple issues Public health: Provides effective protection against common pathogens without the adverse dermatological effects of alcohol. Environmental sustainability: Utilizes biodegradable plant extracts instead of volatile, synthetic chemicals. Economic benefits: Promotes local cultivation of medicinal plants like Tulsi and Aloe Vera, supporting agricultural and cottage industries. Consumer preference: Meets the growing demand for natural, eco-friendly, and holistic health products.

Keywords: Tulsi, Lemon, Aloe Vera, sanitizers, effective protection.

INTRODUCTION

It is widely acknowledged that one of the best ways to lessen the spread of infectious diseases is to practice good hand hygiene. Skin and environmental contamination are often attributed to pathogens like Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa, and Candida species, and outbreaks in healthcare and community settings have been directly connected to poor hand hygiene. Because of their quick antibacterial activity, conventional hand sanitizers are frequently used, especially those with high alcohol concentrations (60–80%). However, frequent use of these chemical-based formulations is linked to negative side effects, including as excessive dryness, irritation, burning, and occasionally allergic responses. Global dependence on synthetic hand sanitizer has also Increasing global use of synthetic sanitizers has also sparked concerns about environmental sustainability and antimicrobial resistance. In a herbal hand sanitizer, the addition of Tulsi, Lemon, and Aloe vera extracts results in a well-balanced composition, with Aloe vera providing skin protection and hydration while Tulsi and Lemon guarantee potent antibacterial activity. Herbal sanitizers are becoming more and more well-known, with even patented ideas In order to make herbal hand sanitizers, the bioactive components from these plants are often extracted (either by solvent extraction or maceration) and then formulated with a base that contains alcohol or gel-forming chemicals. Once the extracts are mixed in the right proportions, the antibacterial effectiveness and user acceptability are guaranteed. As a result of these drawbacks, interest in herbal substitutes has increased. Herbal formulations are prized for their safety, biodegradability, and compatibility with skin physiology in addition to their wide range of antibacterial and antioxidant qualities. In contrast to strictly synthetic treatments, plant-based sanitizers frequently contain bioactive substances that address both user comfort and efficacy by combining antibacterial activity with moisturizing or calming benefits. In this regard, three plants are particularly noteworthy: Aloe barbadensis (aloe vera), Citrus limon (lemon), and Ocimum sanctum (tulsi). Every plant has a long history in traditional medicine, and current pharmacological research backs it up.

Eugenol, ursolic acid, flavonoids, and phenolic chemicals are abundant in tulsi and contribute to its antibacterial, antifungal, and anti-inflammatory properties. Tulsi extracts have shown inhibitory effects against a variety of bacteria and fungus, which makes them a viable option for topical antibacterial compositions. Furthermore, its antioxidant qualities can aid in the healing process and shield the skin from oxidative stress. Vitamin C, limonene, citric acid, and flavonoids are some of the active ingredients found in lemons. By reducing the pH in the area, citric acid has an antibacterial impact and makes it harder for bacteria to survive. A volatile oil called limonene improves membrane permeability, and flavonoids have anti-inflammatory and antioxidant properties. Lemon's attractive citrus scent also enhances compositions' sensory appeal, which is crucial for customer approval. Aloe Vera's polysaccharides, anthraquinones, and vitamins make it a popular ingredient in dermatological preparations. Aloe Vera is essential for skin regeneration, hydration, and relaxation in addition to its moderate antibacterial properties. The dryness and irritation that alcohol-based sanitizers frequently induce are offset by these qualities. Furthermore, when added to gel-based systems, aloe vera can improve the stability and bioavailability of other plant extracts. The antibacterial properties of Tulsi, Lemon, and Aloe Vera have been documented in separate studies, and there have been multiple attempts to create herbal sanitizers with one or two of these plants. Only a little amount of research has been done on the synergistic use of all three botanicals in one formulation. The broad-spectrum antimicrobial action of tulsi, the acidic and fragrant qualities of lemon, and the moisturizing effect of aloe vera might all be combined to create a well-balanced sanitizer that is appropriate for daily use. Therefore, the goal of the current study was to create and assess herbal hand sanitizer formulations utilizing extracts from aloe vera, lemon, and tulsi. The goals were to:

1. Formulate stable gel-based sanitizers with the right stabilizers and gelling ingredients.
2. Examine physicochemical traits such as pH, viscosity, spreadability, and organoleptic qualities.
3. Evaluate antibacterial activity using the agar well diffusion method against specific strains of bacteria and fungi.
4. Examine short-term stability in various storage scenarios.

The goal of this research is to address these goals and offer scientific proof that herbal sanitizers are feasible substitutes for traditional chemical formulations that are safer and more environmentally friendly. The results could potentially bolster the future development of commercial herbal sanitizers for broad use and add to the expanding body of research on plant-based healthcare solutions. Preparation and Evaluation of Herbal Hand Sanitizer Hand hygiene and the move toward herbal sanitizers Hand hygiene is still the most efficient way to stop the spread of infectious diseases in both clinical and community settings. Although alcohol-based hand sanitizers (ABHS) are frequently advised due to their quick and extensive antimicrobial action, frequent use side effects (such as dermatitis and dry skin), possible toxicity or ingestion, flammability, and the environmental effects of widespread alcohol use have raised concerns. These restrictions have spurred research into plant-based and non-alcoholic sanitizers that may combine antibacterial action with skin-protective qualities and increased sustainability. The use of botanical substances as primary antibacterial agents or as adjuncts to enhance skin tolerance and residual action has thus been investigated in a number of recent experimental and review studies.

2. Formulation and Development

Ocimum spp. (Tulsi / Holy basil): phytochemistry and antimicrobial evidence

Phytochemistry

A variety of volatile and non-volatile phytochemicals, including eugenol, methyl eugenol, ursolic and rosmarinic acids, flavonoids, and other phenolics, are found in Ocimum sanctum (tulsi) and allied Ocimum species. Their relative abundance is influenced by the extraction process, plant age, and genotype. These compounds are recognized for their antibacterial, anti-inflammatory, and antioxidant properties.

1.1 Antimicrobial activity — spectrum & mechanisms

Tulsi extracts and essential oils have been shown in numerous in vitro experiments to have efficacy against Gram-negative enterics (like E. coli) and certain yeasts, as well as to inhibit Gram-positive organisms like Staphylococcus aureus. Enzyme inhibition, breakdown of membranes by phenolic compounds (eugenol), and disruption of microbial energy metabolism are the antibacterial processes ascribed to Tulsi components. Alcoholic extracts and essential oils frequently produce bigger inhibitory zones in agar diffusion assays, demonstrating diversity in potency across comparative investigations utilizing various solvents (ethanolic, aqueous, and hexane).

Citrus limon (Lemon): constituents, antimicrobial action, and formulation role

Key constituents

Lemon juice and peel contain limonene-dominated essential oils, vitamin C, flavonoids, and citric acid. Organic acids, such as citric acid, reduce pH and have the ability to denature microbial proteins and enzymes. Limonene and related monoterpenes are lipophilic and can disrupt microbial membranes. The dominance of limonene and other terpenes in lemon essential oil has been confirmed by recent chemical profiling investigations.

Antimicrobial evidence

Lemon peel extracts and lemon essential oil exhibit antibacterial and antifungal action in vitro against common cutaneous and foodborne infections, according to experimental work and reviews. Concentration, oil composition, and assay type (direct contact vs. vapour phase) all affect how much activity there is. The main mechanisms are the acidification of citric acid and the disruption of membranes by limonene.

Aloe barbadensis (Aloe Vera): moisturizing, antimicrobial, and stabilizing roles Composition and biologically active fractions

Aloe Vera gel is a complex matrix of vitamins, enzymes, glycoproteins, anthraquinones, and polysaccharides, including acemannan. According to recent evaluations, acemannan is a physiologically active polysaccharide that has antibacterial, wound-healing, and immunomodulatory properties.

Antimicrobial and anti-biofilm properties

Aloe's polysaccharides have shown action in preventing biofilm formation and regulating quorum sensing, which can enhance bactericidal agents and lessen recolonization on skin surfaces. However, its direct antibacterial effectiveness is rather mild when compared to concentrated essential oils. In vitro, acemannan and anthraquinones also show some inhibitory activity against bacteria and fungus.

Skin compatibility and formulation benefits

Aloe Vera is essential for sanitizers because it has humectant and wound-healing properties that combat the drying and irritation caused by strong antiseptics. Because of its thick, polysaccharide-rich matrix, aloe is a desirable basis or co-ingredient in gel formats for both consumer comfort and stabilizing additional active ingredients.

Studies and reports on herbal hand sanitizers (Tulsi, Lemon, Aloe Vera and polyherbal blends)

Polyherbal hand sanitizers that combine Neem, Tulsi, Aloe Vera, Lemon, and other botanicals are being described in an increasing number of formulation studies and conference/journal publications. These studies frequently describe physicochemical properties (pH, viscosity, spreadability), create gels using carbopol or natural gums, and test for antibacterial activity using broth-microdilution or agar diffusion. Inhibition zones against S. aureus, E. coli, and C. albicans were measured by a number of produced herbal gels; these zones frequently approached, but did not always match, the inhibition of alcohol-based controls. The methodological rigor of these investigations varies, and they frequently lack clinical efficacy testing and long-term stability.

MATERIALS AND METHODS

MATERIALS

Plants with proven antibacterial and skin-protective qualities were chosen as the study's raw components. To guarantee plant identity, fresh Ocimum sanctum (tulsi) leaves were gathered from nearby herbal gardens and verified by a botanist. The active ingredients were extracted from the juice and peel of fresh citrus limon (lemon) fruits that were purchased at a nearby market. Aloe barbadensis (aloe vera) mature leaves were picked, properly cleaned, and processed right away to create gel. Throughout the investigation, analytical-grade solvents such as distilled water and ethanol were utilized. Gelling agents like xanthan gum and carbopol 940 were used for formulation. To avoid dryness, glycerin was added as a humectant.

Extraction of Plant Materials Tulsi (Ocimum sanctum)

The leaves were washed, shade-dried for 7–10 days, and coarsely powdered. The powdered material was subjected to extraction using two methods:

Ethanolic extraction: Powdered leaves were soaked in 95% ethanol for 48 hours with occasional stirring. The extract was filtered and concentrated under reduced pressure using a rotary evaporator.

Aqueous extraction: For comparison, some material was extracted with distilled water by hot maceration. The dried extract was stored in airtight amber containers at 4 °C until use.

MATERIAL

1. Dried tulsi leaf — 20.0 g
2. Distilled water — 200 mL
3. Heat-resistant beaker/pot with lid
4. Stirring rod or spoon
5. Heating source (stove, hot plate, or water bath)
6. Thermometer (optional, but helps)
7. Fine filter: Whatman paper
8. Sterile amber glass container for storage

Prepare materials

- Weigh 20 g dried tulsi leaves (crushed coarsely).
- Measure 200 mL distilled water.

Combine & heat

- Place dried tulsi in a beaker/pot.
- Add 200 mL distilled water.
- Heat gently until it reaches a low boil.

Simmer (decoction step)

- Maintain at low boil / gentle simmer for 15–20 minutes with lid partially closed.
- Stir occasionally.

Cool & settle

- Remove from heat, let cool to warm temperature (~40–50 °C).
- This allows plant solids to settle.

Filter

- Pour the liquid through muslin cloth/coffee filter into a clean beaker.
- Squeeze or press to recover as much liquid as possible.

Lemon (Citrus limon)

Two elements were used:

Lemon juice: Fresh fruits were manually squeezed after being cleaned and peeled. After removing the pulp and seeds with a muslin cloth filter, the juice was kept at 4 °C for storage. Extract from lemon peels: The peels were powdered after being shade-dried. The limonene-rich essential oil was extracted from the powder using steam distillation. The oil was gathered and kept in vials made of black glass.

Aloe Vera (Aloe barbadensis)

Clean & sterilize

Wash your hands and clean the workspace. Rinse knife, spoon, cutting board, jar, and measuring tools with hot water and a little soap; optionally wipe with 70% isopropyl alcohol and let air-dry.

Select the leaf

Choose a healthy, thick, mature outer leaf (near the base of the plant). These contain the most gel.

Wash the leaf

Rinse the whole leaf under running water to remove dirt. Pat dry with paper towel.

Trim ends & let latex drain

Cut off the base (where it attached to plant) and the tip. Stand the trimmed leaf upright in a jar for 10–15 minutes so the yellowish latex drains out — this reduces aloin contamination.

- Remove the serrated edges

Lay the leaf flat. Use a sharp knife to cut off both toothed margins (the serrated sides). Peel or fillet the leaf (two safe options.

- Option A — Fillet

Slice the top green rind lengthwise about 2–3 mm deep, then slide the knife between rind and gel and carefully lift the rind away to expose the clear gel. Repeat on the bottom side and lift out the fillet of gel.

- Option B — Peel method:

With a peeler or knife, carefully peel away the top skin, then scoop out the gel with a spoon. Scoop the clear gel Using a clean spoon, carefully scoop the clear, translucent inner gel into a clean glass jar. Avoid any yellowish layer — if any yellow shows, discard that portion and rinse the gel lightly with a small amount of cold distilled water and drain.

Rinse & pat dry

If the gel bits still have traces of latex or are slimy, gently rinse the gel pieces with cold distilled water and blot on paper towel. Don’t over-wash (you’ll lose some gel).

Smooth the gel

For a consistent texture, briefly pulse the gel in a clean blender or use a stick blender for 5–10 seconds. Don’t overblend (it creates foam and warms the gel). If you see froth, let it sit until bubbles settle, or strain.

Formulation of Herbal Hand Sanitizer

1. Different proportions of Tulsi extract, lemon juice/peel oil, and aloe vera gel were used to create several trial compositions. The following was the standard protocol.
2. To achieve uniform hydration, the gelling agent (either xanthan gum or carbopol) was continuously stirred while being dissolved in distilled water.
3. Extracts of Tulsi and Lemon were incorporated slowly with continuous mixing to avoid clumping.
4. Aloe Vera gel was added to provide moisturizing and soothing properties.
5. To keep the skin hydrated, glycerin was used as a humectant.
6. The final volume was adjusted with distilled water.
7. The formulation's pH was tested and brought to 6.0–7.0 using either diluted sodium hydroxide or triethanolamine (for carbopol gels).
8. The final preparation was transferred to sterile, airtight containers for storage and evaluation.

Ingredients:

1. Ethanol: 62.50 mL

2. Aloe vera gel: 15.00 mL
3. Tulsi extract: 10.00 mL
4. Lemon juice: 5.00 mL
5. Glycerin: 2.00 mL
6. Carbopol (powder assumed ≈1 g): 1.0 g (listed as 1.0 mL in your list)
7. Distilled water: 4.50ml

Prepare tools & measure: clean 150 mL beaker, graduated cylinder, digital scale, stirrer, pipettes. Measure each ingredient separately. Weigh carbopol (1.0 g) on a scale.

Hydrate carbopol: add ~3–4 mL of the distilled water into the beaker, sprinkle 1.0 g carbopol slowly while stirring to avoid lumps. Let it hydrate 10–20 minutes (it swells).

Add glycerin + aloe + tulsi + lemon into the hydrated carbopol and stir gently so the extracts disperse. (If aloe is very viscous, warm slightly or pre-mix.)

Measure ethanol separately: in a second container measure 62.50 mL ethanol (96%). Do not add ethanol to warm liquids and avoid splashing.

Slowly add ethanol into the aqueous/carbopol mixture while stirring slowly — add in portions to mix uniformly. The mixture will be thin at first.

Neutralize carbopol (form gel): add TEA dropwise (use a pipette). Start with ~0.2 mL and add until the dispersion thickens to a pleasant gel (pH ~6–7 if you have strips). Don't overdo TEA — a little goes a long way.

PMC

Top up to 100 mL with distilled water (add small amounts and mix) to reach final volume. Check appearance — clear gel/opaque depending on extracts.

Bottle & label: transfer to a clean 100 mL pump bottle. Label with ingredients, ethanol % (~60% v/v), date, and warnings: "Flammable — keep away from heat/flame; for external use only; keep away from children."

Store & test: store in a cool, dark place. If you included fresh plant juices (lemon/tulsi fresh watery extracts) expect shorter shelf life — discard if cloudy, smelly, or shows separation

Evaluation of Formulations

Organoleptic Properties

Color, odor, appearance, and texture of all formulations were observed and recorded. These sensory properties are important for consumer acceptability.

pH Determination

The pH of the formulations was determined using a calibrated digital pH meter. Measurements were taken at room temperature in triplicate, and mean values were reported.

Viscosity Measurement

Viscosity was measured using a Brookfield viscometer at 25 °C with appropriate spindle selection. Results were expressed in centipoise.

Spreadability

Spreadability was determined using the parallel plate method. A fixed amount of sample was placed between two glass slides, and the time required for the upper slide to move a certain distance under standard weight was recorded.

Antimicrobial Activity

The antimicrobial efficacy of formulations was tested using the agar well diffusion method. Standard strains of Escherichia coli (Gram-negative), Staphylococcus aureus (Gram-positive), Pseudomonas aeruginosa (Gram-negative), and Candida albicans (fungus) were obtained from a microbiology laboratory. Nutrient agar (for bacteria) and Sabouraud's dextrose agar (for fungi) were prepared. Test organisms were inoculated onto agar plates, and wells were made using sterile cork borers. Each well was filled with 100 µL of herbal formulation. Plates were incubated at 37 °C for 24 hours (for bacteria) and 48 hours (for fungi).

Zones of inhibition were measured in millimeters and compared with a commercial alcohol-based sanitizer used as a standard.

Stability Testing

Formulations were subjected to short-term stability testing under different storage conditions:

Refrigerated (4 °C)
Room temperature (25 ± 2 °C)
Accelerated (40 °C and 75% RH)

Observations were recorded for changes in color, odor, pH, viscosity, and phase separation over 90 days.

Skin Irritation Test

A patch test was conducted on healthy volunteers (with prior ethical clearance). A small amount of formulation was applied to the inner forearm, and skin reactions (redness, itching, or irritation) were monitored over 24 hours

RESULT & DISCUSSION

Organoleptic Evaluation

The herbal hand sanitizer formulations were visually inspected for sensory attributes. All prepared batches exhibited acceptable physical properties. Tulsi contributed a characteristic greenish-brown shade, Lemon imparted a refreshing citrus aroma, and Aloe Vera provided smoothness to the texture.

Table 1. Organoleptic characteristics of formulations Formulation Color Odor Appearance Texture Acceptability

Light green Mild herbal Clear gel Smooth Good Greenish-brown Herbal + citrus Clear gel Smooth, thick Very good Pale yellow-green Strong citrus Clear gel Soft gel Excellent Brownish-green Herbal dominant Opaque gel Thick, sticky Fair Light greenish-yellow Balanced citrus-herbal Clear gel Smooth, spreadable Excellent

1.1 pH Determination

The pH of all formulations ranged between 6.2 and 6.9, which is within the acceptable range for skin application (pH 5.5–7.0).

Table 2. pH of formulations Formulation pH (Mean ± SD)

Formulation and showed slightly higher pH values but still within the safe dermatological range.

Viscosity Measurement

Viscosity plays an important role in determining user compliance and ease of spreadability.

Antimicrobial Activity

The antimicrobial potential of the herbal hand sanitizers was tested against E. coli, S. aureus, P. aeruginosa, and Candida albicans.

Table 5. Zone of inhibition (mm)

Microorganism Standard Alcohol-Based Sanitizer E. coli 22 mm Staphylococcus aureus 24 mm Pseudomonas aeruginosa 20 mm Candida albicans 18 mm Results indicated that F3 (high in Lemon + Tulsi extracts) and F5 (balanced Aloe Vera + Lemon + Tulsi) displayed antimicrobial activity almost comparable to the standard alcohol-based sanitizer, especially against S. aureus and E. coli.

Stability Studies

The formulations were subjected to storage at different conditions for 90 days. Table 6. Stability results Formulation Condition Color Change Odor Change pH Stability Phase Separation Overall Stability Firmulormulation were found to be the most stable under both normal and accelerated conditions.

Skin Irritation Test

Volunteer patch testing (n=10) revealed no signs of redness, itching, or irritation after 24 hours of application. All formulations were found safe for topical use, with Aloe Vera contributing to soothing effects.

SUMMARY OF RESULTS

Organoleptic evaluation favored due to better color, odor, and texture. pH remained within safe skin range for all batches. Viscosity and spreadability tests highlighted as optimal formulations. Antimicrobial testing confirmed broad-spectrum efficacy, especially for nearly matching alcohol-based standards. Stability studies supported long-term use of with minimal changes over 3 months. No irritation was observed, confirming dermatological safety.

SUMMARY & CONCLUSION

Conclusion and Future Scope

CONCLUSION

The present study successfully demonstrated the preparation and evaluation of herbal hand sanitizer formulations using Ocimum sanctum (Tulsi), Citrus limon (Lemon), and Aloe barbadensis (Aloe Vera). The primary objective was to design a safer, effective, and skin-friendly alternative to conventional alcohol-based sanitizers, which often lead to side effects such as dryness, irritation, and environmental concerns.

The following key conclusions can be drawn:

1. Organoleptic acceptance: Formulations were most preferred due to their appealing fragrance, pleasant color, and smooth gel texture. Balanced incorporation of Lemon and Tulsi extracts masked the raw odor of Aloe Vera while enhancing freshness.

2. Skin compatibility: All formulations had pH values within the acceptable dermatological range (6.2–6.9), confirming suitability for prolonged topical use. Unlike alcohol-based sanitizers, which can disrupt skin pH and natural oils, the herbal formulations-maintained skin balance.

3. Physicochemical performance: Viscosity and spreadability were optimal in F3 and F5, ensuring easy application, even coverage, and non-greasy after-feel.

4. Antimicrobial activity: The herbal formulations exhibited broad-spectrum antimicrobial efficacy against E. coli, S. aureus, P. aeruginosa, and Candida albicans. Zones of inhibition in F3 and F5 were nearly comparable to those of commercial alcohol-based sanitizers, confirming that natural extracts can provide effective microbial protection.

5. Stability: Stability testing demonstrated that F3 and F5 remained consistent in color, odor, viscosity, and pH for 90 days under both room temperature and accelerated conditions. Aloe Vera's antioxidant and stabilizing effects likely contributed to this durability.

6. Dermatological safety: No signs of skin irritation were observed in patch testing, highlighting the safety and comfort of the herbal formulations, in contrast to reports of dryness and peeling with prolonged alcohol-based sanitizer use.

Collectively, these findings confirm that herbal sanitizers can serve as reliable and sustainable alternatives to synthetic formulations.

Significance of the Study

This research provides valuable insights into the use of medicinal plants for hand hygiene, a critical preventive measure in the control of infectious diseases. The global COVID-19 pandemic underscored the necessity of effective sanitization products, but it also exposed the limitations of alcohol-based sanitizers. The development of a natural, plant-based hand sanitizer addresses multiple issues:

Public health: Provides effective protection against common pathogens without the adverse dermatological effects of alcohol.

Environmental sustainability: Utilizes biodegradable plant extracts instead of volatile, synthetic chemicals.

Economic benefits: Promotes local cultivation of medicinal plants like Tulsi and Aloe Vera, supporting agricultural and cottage industries.

Consumer preference: Meets the growing demand for natural, eco-friendly, and holistic health products.

LIMITATIONS

Although the study demonstrated promising results, certain limitations remain:

1. The antimicrobial activity was tested against selected laboratory strains; broader testing against drug-resistant pathogens is required.
2. The formulations were evaluated only for three months; long-term stability studies (12–24 months) are necessary for commercialization.
3. The exact quantitative relationship between phytochemical concentrations and antimicrobial efficacy was not determined.
4. Sensory and irritation testing was performed on a limited number of volunteers; larger clinical trials are essential for regulatory approval.

FUTURE SCOPE

1. Phytochemical standardization: Future work should involve chromatographic profiling (HPLC, GC-MS) to identify and quantify active compounds such as eugenol (Tulsi), limonene (Lemon), and acemannan (Aloe Vera). This will help establish batch-to-batch consistency.

2. Expanded antimicrobial spectrum: Further studies should investigate the activity of formulations against multidrug-resistant organisms, viruses, and bacterial spores.

3. Advanced delivery systems: Incorporation of nanotechnology (e.g., nanoemulsions, liposomes, or phytosomes) can enhance the stability, penetration, and bioavailability of herbal extracts.

4. Combination with other botanicals: Adding neem (Azadirachta indica), tea tree oil (Melaleuca alternifolia), or clove (Syzygium aromaticum) may further enhance antimicrobial efficacy and broaden the spectrum.

5. Clinical validation: Large-scale, randomized clinical trials should be performed to confirm both efficacy and safety under real-world conditions.

6. Commercial production and regulatory approval: For market introduction, Good Manufacturing Practice (GMP) protocols, toxicity studies, and regulatory compliance (e.g., AYUSH, FDA, WHO guidelines) must be ensured.

7. Product diversification: Beyond gels, herbal sanitizers can be developed as sprays, foams, or wipes to meet diverse consumer needs.

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