International Journal of Pharmacognosy and Clinical Research

ISSN Print: 2664-763X
ISSN Online: 2664-7648
Impact Factor: RJIF 8.25
IJPCR 2026; 8(1): 25-30
www.pharmacognosyjournal.in
Received: 14-11-2025
Accepted: 18-12-2025

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Beyond Alcohol: A systematic review of the antibacterial efficacy and formulation parameters of plant-derived sanitizers

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DOI: https://www.doi.org/10.33545/2664763X.2026.v8.i1a.85

Abstract
Hand hygiene is the primary defense against infectious diseases, yet the frequent use of alcohol-based sanitizers often leads to skin irritation and environmental concerns. This has necessitated the development of herbal alternatives that are both safe and effective. This review evaluates the phytochemical profiles, formulation techniques, and efficacy of plant-based hand sanitizers through a systematic analysis of research from standard journals. The study focuses on plants such as Neem (*Azadirachta indica*), Tulsi (*Ocimum sanctum*), and Turmeric (*Curcuma longa*). Bioactive compounds, including azadirachtin, eugenol, and curcumin, demonstrate potent antimicrobial action by disrupting microbial membranes. Formulations enhanced with Aloe Vera and Glycerin provide superior skin hydration compared to synthetic variants. While herbal sanitizers are biodegradable and skin-friendly, challenges include the standardization of extracts and a slower microbial "kill time." Ultimately, herbal hand sanitizers serve as a viable, eco-friendly substitute for long-term hygiene, offering therapeutic benefits alongside disinfection. Future advancements in nanotechnology, such as nano-emulsions, are expected to further optimize their antimicrobial performance and stability for global healthcare applications.

Keywords: Herbal hand sanitizer, antimicrobial, phytochemicals, polyherbal, skin hygiene

1. Introduction

- **Background:** Hand hygiene is universally recognized as the single most effective measure for preventing the spread of transmissible pathogens and reducing the burden of healthcare-associated infections [1]. The practice gained critical prominence during global health emergencies, such as the COVID-19 pandemic and seasonal influenza outbreaks, where it served as a primary intervention to interrupt viral transmission via contact with contaminated surfaces or respiratory secretions [2]. Public health authorities worldwide continue to mandate frequent hand sanitization as a standard protocol to mitigate the risk of acquiring communicable diseases in both community and clinical settings [3].
- **Current Market:** Currently, alcohol-based hand sanitizers (ABHS) containing ethanol or isopropanol are the dominant commercial formulations due to their rapid antimicrobial action and broad-spectrum efficacy [4]. Despite their popularity, the frequent and prolonged application of high-concentration alcohol formulations is frequently associated with adverse dermatological effects, including skin dryness, irritation, fissures, and allergic contact dermatitis [5]. Furthermore, significant safety concerns have been raised regarding ABHS due to their high flammability and the risk of acute toxicity or poisoning upon accidental ingestion, particularly in children [6].
- **Need for Herbal Alternatives:** In response to these limitations, there is a growing consumer demand for natural, eco-friendly, and sustainable personal care products that avoid harsh synthetic chemicals [7]. Herbal hand sanitizers have emerged as a viable alternative, leveraging the bioactive compounds of medicinal plants to provide antimicrobial protection while simultaneously offering skin-conditioning and moisturizing benefits [8].

These botanical formulations are increasingly favoured for their biodegradable nature, lower toxicity profile, and ability to minimize the skin barrier damage often caused by repeated alcohol exposure [9].

- **Objective:** The primary objective of this review is to systematically evaluate the phytochemistry, antimicrobial efficacy, and safety profiles of various herbal ingredients used in the formulation of natural hand sanitizers [10]. This article further aims to compare the performance of these polyherbal formulations against standard synthetic agents to determine their feasibility for widespread public use [11].

2. Key Herbal Ingredients & Their Phytochemistry

The efficacy of herbal hand sanitizers relies heavily on the synergistic action of bioactive phytochemicals extracted from medicinal plants [12]. These ingredients are generally categorized based on their functional role in the formulation, ranging from antimicrobial activity to skin conditioning and preservation [13].

2.1. Antimicrobial Agents

2.1.1 Neem (*Azadirachta indica*)

Neem has been extensively studied for its broad-spectrum antibacterial and antiviral properties, primarily attributed to its complex isoprenoids [14]. The primary bioactive compounds, including the limonoids azadirachtin and nimbidin, exert antimicrobial effects by disrupting the microbial cell wall and interfering with bacterial protein synthesis [15]. Research indicates that ethanolic extracts of Neem leaves demonstrate significant inhibition against common skin pathogens such as *Staphylococcus aureus* and *Escherichia coli*, making it a cornerstone ingredient in polyherbal sanitizers [14].

2.1.2 Tulsi (*Ocimum sanctum*)

Known as "Holy Basil," Tulsi possesses potent antiseptic qualities driven by its volatile oil components [16]. The major phytochemicals responsible for its efficacy are eugenol (1-hydroxy-2-methoxy-4-allylbenzene) and carvacrol, which facilitate the leakage of cellular content by damaging the cytoplasmic membrane of bacteria [17]. Furthermore, studies have shown that linoleic acid and ursolic acid present in Tulsi extracts contribute to its ability to neutralize free radicals and suppress viral replication, providing a dual mechanism of protection [16].

2.1.3 Turmeric (*Curcuma longa*)

Turmeric is incorporated into herbal formulations not only for its color but for the powerful biological activity of curcumin, a hydrophobic polyphenol [18]. Curcumin exhibits bactericidal activity by inhibiting the bacterial cell division protein FtsZ, effectively arresting bacterial growth without causing toxicity to human cells [19]. Additionally, its strong anti-inflammatory and antioxidant properties help mitigate skin irritation that might occur from frequent hand washing [18].

2.2. Moisturizing & Soothing Agents

2.2.1 Aloe Vera (*Aloe barbadensis miller*)

To counteract the stripping of natural skin oils, Aloe Vera is frequently added as a emollient and hydrating agent [20]. Its efficacy stems from a rich concentration of mucopolysaccharides (such as acemannan), which create a protective barrier on the stratum corneum to prevent transepidermal water loss [21]. Aloe gel also contains carboxypeptidases and bradykinase, enzymes that reduce inflammation and soothe the skin upon application [20].

2.2.2 Glycerin

While not a herb, Glycerin (glycerol) is a standard, plant-derived compatible solute often paired with herbal extracts as a primary humectant [22]. It functions by drawing moisture from the environment into the skin layers, thereby maintaining skin elasticity and preventing the dermatitis often associated with volatile herbal extracts or alcohol bases [22].

2.3 Fragrance & Preservatives

Essential Oils (Lemon, Orange, Rose, Clove)

Natural essential oils serve a dual purpose as fragrancing agents and bio-preservatives due to their high terpene and phenolic content [23]. Lemon and Orange oils are rich in limonene, which provides a refreshing citrus scent while exhibiting oxidative stress-mediated antimicrobial activity [24]. Clove oil contributes additional eugenol, enhancing the overall antimicrobial potency of the formulation, while Rose water (containing phenylethanol) offers a mild fragrance and astringent properties that stabilize the formulation against spoilage [25].

3. Formulation and Preparation Methods

The development of an effective herbal hand sanitizer involves a multi-stage process, beginning with the isolation of bioactive constituents and concluding with the stabilization of the final delivery system [10]. The choice of extraction method and vehicle significantly influences the antimicrobial potency and physicochemical stability of the final product [26].

3.1 Extraction Techniques

The efficacy of the sanitizer depends heavily on the yield and purity of the phytochemicals extracted from the raw plant material [27].

- **Maceration:** This is the most common and cost-effective method used for thermolabile herbal ingredients [28]. It involves soaking coarse plant powders in a solvent (menstruum) such as ethanol or distilled water at room temperature for a defined period (typically 3–7 days) with frequent agitation to facilitate the dissolution of active principles [29].
- **Soxhlet Extraction:** For exhaustive extraction of heat-stable compounds, the Soxhlet apparatus is employed. This continuous hot extraction method utilizes a volatile solvent that is repeatedly vaporized and condensed, ensuring maximum recovery of lipophilic constituents like alkaloids and glycosides from the plant matrix [30].
- **Steam Distillation:** This technique is specifically reserved for isolating volatile essential oils (e.g., from Clove or Tulsi) [31]. It operates on the principle that steam vaporizes the plant's volatile compounds at temperatures lower than their boiling points, preventing the degradation of aromatic therapeutic agents [31].

3.2 Types of Formulations

Herbal sanitizers are formulated into various delivery systems to enhance user compliance and bioavailability [8].

- **Gels:** Gel-based formulations are the most popular due to their longer retention time on the skin [32]. These are typically prepared using synthetic polymers like Carbopol 940 or Carbopol 980 as gelling agents, which form a transparent matrix when dispersed in water [33]. A neutralizing agent, such as Triethanolamine (TEA), is added dropwise to adjust the pH to 6.0–7.0, triggering cross-linking that results in the characteristic viscous gel structure [33].
- **Liquid Sprays:** These low-viscosity solutions are designed for rapid application and quick drying [34]. They are prepared by simply dissolving herbal extracts and essential oils in the solvent base, often requiring a solubilizer (like Polysorbate 20) to ensure the uniform dispersion of hydrophobic oils in aqueous media [34].
- **Foam-based Sanitizers:** Foam formulations are gaining traction as they cover a larger surface area with less product volume [7]. These require the addition of surfactants or foaming agents that lower surface tension, allowing the liquid to aerate when dispensed through a specialized pump [35].

3.3 Base Selection
The solvent system, or "base", serves as the carrier for the herbal extracts and dictates the product's primary antimicrobial mechanism [26].

- **Hydro-Alcoholic Base:** Most commercial herbal sanitizers utilize a hydro-alcoholic base containing 60–80% v/v ethanol or isopropyl alcohol [11]. In these formulations, the alcohol acts as the primary rapid-acting germicide, while the herbal extracts provide prolonged residual protection and reduce the harsh effects of the alcohol [36].
- **Aqueous (Alcohol-Free) Base:** For users with sensitive skin or for pediatric use, alcohol-free bases are developed using water as the primary solvent [37]. These formulations rely entirely on the high concentration of antimicrobial herbal extracts (e.g., Neem, Lemon oil) or alternative biocides like Benzalkonium Chloride for efficacy, though they typically require longer contact time to achieve the same log reduction of pathogens as alcohol-based counterparts [37].

4. Evaluation Parameters
The standardization of herbal hand sanitizers is essential to ensure that the final product is safe for human application and effective against target pathogens [32]. Evaluation follows rigorous protocols to determine the physical, chemical, and biological integrity of the formulation [10].

4.1 Organoleptic Properties
The sensory characteristics of the sanitizer are the first indicators of consumer acceptance and formulation consistency [34].

- **Color and Odor:** The formulation is visually inspected for its characteristic color, which should remain stable without significant darkening or precipitation [32]. The odor is assessed to ensure it possesses the pleasant, natural fragrance of the incorporated essential oils, such as Lemon or Rose, rather than a pungent chemical smell [8].
- **Clarity and Texture:** The clarity is measured by visual transparency against a dark and light background to check for the presence of suspended particles or turbidity [33]. Texture analysis ensures the product is non-sticky and smooth upon application to the skin [11].

4.2 Physicochemical Properties
These parameters dictate the stability and user-friendliness of the product during its intended shelf life [26].

- **pH Measurement:** The pH of the sanitizer is a critical factor for skin compatibility and is measured using a digital pH meter [32]. Ideally, the pH should be maintained between 5.5 and 7.0 to mimic the natural acid mantle of the skin, thereby preventing irritation and dryness [38].
- **Viscosity and Spreadability:** Viscosity is typically determined using a Brookfield viscometer to ensure the gel or liquid has the appropriate flow behavior for dispensing [33]. Spreadability is assessed by measuring the diameter of the area covered by a specific amount of the formulation between two glass plates under a standard weight, which indicates the ease of application [39].
- **Stability Studies:** Formulations undergo accelerated stability testing according to ICH guidelines, where they are exposed to varying temperatures (e.g., 4°C, 25°C, and 40°C) and humidity levels for several months [40]. This ensures that the herbal extracts do not degrade and the emulsion or gel structure does not undergo phase separation over time [40].

4.3 Biological Testing
Biological evaluation confirms the therapeutic claims and safety of the herbal ingredients [17].

- **Antimicrobial Efficacy:** The primary method for evaluating potency is the Agar Well Diffusion Method, where the Zone of Inhibition (ZOI) is measured in millimeters [41]. The sanitizer is tested against representative Gram-positive bacteria like *Staphylococcus aureus* and Gram-negative bacteria like *Escherichia coli* to determine its broad-spectrum capability [41].
- **Skin Irritancy Test:** To ensure the product is safe for frequent use, a skin irritation study is conducted, often using a Human Patch Test or an animal model (e.g., New Zealand white rabbits) [42]. The formulation is applied to a localized area, and the site is observed at intervals of 24, 48, and 72 hours for signs of erythema (redness) or edema (swelling) [42].

5. Advantages and Disadvantages
The transition from synthetic formulations to herbal hand sanitizers involves a careful balance between dermatological benefits and pharmaceutical challenges [8]. While botanical products offer a safer profile for long-term use, they present specific technical hurdles regarding standardization and shelf stability [37].

5.1 Advantages
- **Skin-friendly and Non-drying:** Unlike conventional alcohol-based sanitizers that lead to stratum corneum damage, herbal formulations often contain natural emollients like Aloe Vera that preserve the skin’s lipid barrier [21]. The inclusion of these botanical humectants ensures that the skin remains hydrated, significantly reducing the incidence of irritant contact dermatitis [5, 20].

- **Biodegradable and Eco-friendly:** Herbal sanitizers are primarily composed of plant-derived secondary metabolites that undergo rapid biological degradation in the environment [9]. This reduces the chemical footprint and prevents the accumulation of persistent synthetic residues in aquatic ecosystems, which is a common concern with triclosan-based products [6, 43].
- **Therapeutic Benefits:** Beyond simple disinfection, herbal ingredients like Turmeric and Neem offer intrinsic anti-inflammatory and antioxidant properties [14, 18]. These bioactive compounds promote the healing of micro-fissures on the skin surface and provide a protective effect against oxidative stress caused by environmental pollutants [15, 19].

5.2 Disadvantages

- **Shorter Shelf Life and Stability Issues:** Herbal extracts are highly susceptible to oxidation and microbial contamination over time, often resulting in a shorter expiration period compared to synthetic versions [40]. Maintaining the physical consistency and chemical integrity of polyherbal gels requires complex stabilization techniques to prevent phase separation or precipitate formation [33, 39].
- **Variable Efficacy Based on Plant Quality:** The antimicrobial potency of herbal sanitizers is strictly dependent on the concentration of phytochemicals, which varies significantly based on geographic location, soil quality, and harvesting season [27, 44]. This lack of uniformity makes it difficult to achieve consistent "kill rates" across different manufacturing batches without rigorous standardization [10, 44].
- **Slower "Kill Time":** Research indicates that many 100% alcohol-free herbal sanitizers require a longer contact time—often up to 30 to 60 seconds to achieve a significant log reduction in bacterial counts [37, 45]. In contrast, standard 70% isopropyl alcohol formulations provide near-instantaneous denaturation of microbial proteins, making them more efficient in high-risk clinical environments [4, 45].

6. Future Prospects and Conclusion

The evolution of herbal hand sanitizers from traditional home remedies to standardized pharmaceutical products faces both technical obstacles and promising technological advancements [46]. Addressing these factors is essential for the global transition toward sustainable hygiene solutions [47].

6.1 Challenges

The primary hurdle in the commercialization of herbal sanitizers is the standardization of herbal extracts, as the concentration of active secondary metabolites like azadirachtin or eugenol fluctuates due to genetic and environmental factors [44]. This variability necessitates the use of advanced analytical techniques, such as High-Performance Liquid Chromatography (HPLC), to ensure batch-to-batch consistency and therapeutic reliability [48]. Furthermore, large-scale manufacturing presents difficulties in maintaining the stability of volatile essential oils during the heating and mixing phases of industrial production [49]. Economic constraints also arise from the high cost of organic cultivation and the complex purification processes required to remove plant pigments that may stain skin or clothing [49].

6.2 Future Trends

The integration of nanotechnology represents a transformative trend in improving the delivery and performance of botanical antimicrobials [50]. The development of nano-emulsions and polymeric nanoparticles allows for the encapsulation of hydrophobic herbal oils, significantly increasing their surface area and penetration through microbial biofilms [51]. These nano-formulations offer a sustained-release mechanism, which extends the duration of antimicrobial protection on the skin surface compared to traditional aqueous extracts [50]. Additionally, the use of green-synthesized metal nanoparticles (e.g., silver or zinc) capped with plant extracts is being explored to create synergistic "next-generation" sanitizers with enhanced efficacy at lower concentrations [51].

7. Conclusion

Herbal hand sanitizers represent a viable, long-term alternative to synthetic alcohol-based products, particularly for daily community use where skin health is a priority [8, 10]. By combining the potent antimicrobial properties of plants like Neem, Tulsi, and Turmeric with natural humectants like Aloe Vera, these formulations provide effective germ protection while mitigating the risks of dermatitis and environmental toxicity [21, 37]. While challenges regarding rapid "kill time" and shelf-life persist, the application of nanotechnology and rigorous standardization protocols promises to bridge the gap between natural safety and pharmaceutical efficiency [50, 52]. Ultimately, herbal sanitizers align with the global shift toward eco-friendly healthcare, offering a sustainable strategy for personal hygiene and infectious disease prevention [9, 52].

8. Conflict of Interest Statement

The authors affirm that there are no conflicts of interest associated with this work.

9. Data Availability Statement

This published article contains all of the data created or examined during this investigation.

References

1. Australian Commission on Safety and Quality in Health Care. Safety and Quality. Hand washing reduces the spread of germs and saves lives; 2024 May 1.
2. Beale S, Johnson AM, Zambon M, *et al*. Hand hygiene practices and the risk of human coronavirus infections in a UK community cohort. Wellcome Open Res. 2020;5:98.
3. World Health Organization. Handwashing an effective tool to prevent COVID-19, other diseases. WHO South-East Asia News. 2020 Oct 15.
4. Gold NA, Avva U. Alcohol Sanitizer. [Updated 2024 Jan]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024.
5. Alhalwani AY, Alshammari SA, Alshammari F, *et al.* The impact of alcohol hand sanitizer use on skin health between healthcare workers: Cross-sectional study. Skin Res Technol. 2024;30(1):e13567.

6. Mahmood A, Eqan M, Pervez S, *et al*. COVID-19 and frequent use of hand sanitizers; human health and environmental hazards by exposure pathways. Sci. Total Environ. 2020;742:140561.
7. Fortune Business Insights. Hand sanitizer market size, share & industry analysis, by product form (Foam, Gel, and Liquid), by type (Alcohol-based and Alcohol-free), By Distribution Channel, and Regional Forecast, 2024-2032. Fortune Business Insights; 2025.
8. Thombare P, Shinde S. Nature's shield: The promise of herbal hand sanitizers. Int J Sci Healthc Res. 2024;9(4):35-42.
9. Abdel-Aziz SM, Aeron A. Development and evaluation of an eco-friendly hand sanitizer formulation valorized from fruit peels. Sci Rep. 2023;13:22205.
10. Kumar S, Singh A. A comprehensive review on herbal hand sanitizers: formulation and evaluation. World J Pharm Res. 2025;14(5):112-118.
11. Chaudhary P, Gupta R. Natural hand sanitizers: A systematic review on the effectiveness and antimicrobial potential against pathogens. Int. J Res Appl Sci Eng Technol. 2025;13(2):45-50.
12. Chouhan S, Sharma K, Guleria S. Antimicrobial activity of some essential oils-present status and future perspectives. Medicines (Basel). 2017;4(3):58.
13. Thombare P, Shinde S. Nature's shield: the promise of herbal hand sanitizers. Int J Sci Healthc Res. 2024;9(4):35-42.
14. Alzohairy MA. Therapeutics role of *Azadirachta indica* (Neem) and their active constituents in diseases prevention and treatment. Evid Based Complement Alternat Med. 2016;2016:7382506.
15. Heyman L, Houri-Haddad Y, Ginsburg I, *et al*. The anti-bacterial and anti-inflammatory properties of Neem (*Azadirachta indica*) extract. J Herb Med. 2017;15:100234.
16. Cohen MM. Tulsi-*Ocimum sanctum*: A herb for all reasons. J Ayurveda Integr Med. 2014;5(4):251-259.
17. Rathod T, Patel S. Efficacy of *Ocimum sanctum* (Tulsi) extracts in hand sanitizer formulations against nosocomial pathogens. Int J Pharm Sci Res. 2023;14(6):2890-2896.
18. Moghadamtousi SZ, Kadir HA, Hassandarvish P, *et al*. A review on antibacterial, antiviral, and antifungal activity of curcumin. Biomed Res Int. 2014;2014:186864.
19. Teow SY, Liew K, Ali SA, *et al*. Antibacterial action of curcumin against *Staphylococcus aureus*: A brief review. J Trop Med. 2016;2016:2853045.
20. Surjushe A, Vasani R, Saple DG. Aloe vera: A short review. Indian J Dermatol. 2008;53(4):163-166.
21. Rahman S, Carter P. Aloe Vera in hand sanitizers: Mitigating alcohol-induced skin dehydration. Dermatol Ther (Heidelb). 2022;12(5):1105-1112.
22. Becker LC, Bergfeld WF, Belsito DV, *et al*. Safety assessment of glycerin as used in cosmetics. Int J Toxicol. 2019;38(3_suppl):6S-22S.
23. Herman A, Herman AP. Essential oils and their constituents as skin penetration enhancers for transdermal drug delivery: A review. J Pharm Pharmacol. 2015;67(4):473-485.
24. Mancuso M, Santoro I. Limonene: A review of its pharmacological properties and potential in cosmetic formulations. J Essent Oil Res. 2019;31(2):120-128.
25. Nzeako BC, Al-Kharousi ZS, Al-Mahrooqi Z. Antimicrobial activities of clove and thyme extracts. Sultan Qaboos Univ Med J. 2006;6(1):33-39.
26. Joshi D, Gowda V. Formulation and evaluation of polyherbal hand wash and sanitizer. J Pharmacogn Phytochem. 2021;10(3):145-150.
27. Azwanida NN. A review on the extraction methods use in medicinal plants, principle, strength and limitation. Med Aromat Plants. 2015;4:196.
28. Handa SS, Khanuja SP, Longo G, *et al*. Extraction technologies for medicinal and aromatic plants. Trieste: International Centre for Science and High Technology; 2008.
29. Ingle KP, Deshmukh AG, Padole DA, *et al*. Phytochemicals: Extraction methods, identification and detection of bioactive compounds from plant parts. J Pharmacogn Phytochem. 2017;6(1):32-36.
30. Redfern J, Kinninmonth M, Burdass D, *et al*. Using soxhlet extraction to investigate phytochemicals as antimicrobial agents. J Microbiol Biol Educ. 2014;15(1):45-46.
31. Tongnuanchan P, Benjakul S. Essential oils: Extraction, bioactivities, and their uses for food preservation. J Food Sci. 2014;79(7):R1231-R1249.
32. Bonde S, Yeole P. Formulation and evaluation of herbal hand sanitizer. Asian J Pharm Clin Res. 2022;15(4):89-92.
33. Islam MT, Hornedo RN, Ciotti S, *et al*. Rheological characterization of topical carbomer gels neutralized to different pH. Pharm Res. 2004;21(7):1192-1199.
34. Gondal N. Formulation development and evaluation of herbal hand sanitizer spray. Int. J Curr Pharm Res. 2023;15(2):22-26.
35. Argyriadou A, Vakali A. Foam formulations in dermatology: A review. Dermatol Ther. 2020;33(6):e13989.
36. Jain V, Karibasappa GN, Dodamani AS, *et al*. Comparative assessment of antimicrobial efficacy of different hand sanitizers: An *in vitro* study. Dent Res J (Isfahan). 2016;13(5):424-431.
37. Ghaffar A, Yameen M, Kiran S, *et al*. Chemical composition and in-vitro evaluation of a novel herbal alcohol-free hand sanitizer. J Oleo Sci. 2022;71(8):1121-1130.
38. Lambers H, Piessens S, Bloem A, *et al*. Natural skin surface pH is on average below 5, which is beneficial for its resident flora. Int J Cosmet Sci. 2006;28(5):359-370.
39. Deuschle VCN, Deuschle RA, Pertile M, *et al*. Physical-chemical evaluation of herbal hand sanitizers. Braz J Pharm Sci. 2015;51(4):811-817.
40. Bajaj S, Singla D, Sakhuja N. Stability testing of pharmaceutical products. J App Pharm Sci. 2012;2(3):129-138.
41. Balouiri M, Sadiki M, Ibnsouda SK. Methods for *in vitro* antibacterial activity evaluation: A review. J Pharm Anal. 2016;6(2):71-79.
42. OECD. Test No. 404: Acute Dermal Irritation/Corrosion. OECD Guidelines for the Testing of Chemicals, Section 4. Paris: OECD Publishing; 2015.
43. Halden RU. On the need and speed of regulating triclosan and triclocarban in the United States. Environ Sci Technol. 2014;48(7):3603-3611.

44. Pandey A, Tripathi S. Concept of standardization, extraction and characterization of medicinal plant extract. Int J Pharm Front Res. 2014;4(1):1-16.
45. Edmonds-Wilson SL, Nurinova NI, Zapka CA, *et al*. Review of the hand microbiome and effects of hand hygiene practices. Exog Dermatol. 2015;4(1):2-9.
46. Sahu S, Gidwani B, Dhongade HJ. Importance of standardization of herbal drugs in the present scenario. PharmaTutor. 2018;6(11):34-40.
47. Yadav RK, Saini K. Challenges and future prospects in the development of herbal formulations. Int J Pharm Sci Rev Res. 2023;78(2):45-51.
48. Nikam PH, Kareparamban J, Jadhav A, *et al*. Future trends in standardization of herbal drugs. J Appl Pharm Sci. 2012;2(6):38-44.
49. Bhowmick S, Chowdhury S. Industrial scale-up of herbal formulations: Challenges and opportunities. J Pharm Innov. 2024;19(1):12-20.
50. Narasimha G, Sridevi J, Devi PB, *et al*. Nanotechnology in herbal medicines: A review. J Nanomed Nanotechnol. 2021;12(5):568.
51. Anjali S, Rajendran S. Nano-emulsions based herbal hand sanitizers: A review on preparation and antimicrobial efficacy. Nano Express. 2024;5(1):012003.
52. Verma H, Negi AS, Khanna S. Sustainable hygiene: The role of botanical disinfectants in modern healthcare. Front Pharmacol. 2025;16:1042.