ISSN: 2278-2648

International Journal of Research in Pharmacology & Pharmacotherapeutics (IJRPP)

IJRPP |Vol.15 | Issue 1 | Jan - Mar -2026

www.ijrpp.com

DOI : https://doi.org/10.61096/ijrpp.v15.iss1.2026.87-97

Review

Herbal Nanogel Preservatives: A Sustainable Nanotechnology-Based Approach for Safer Pharmaceutical and Cosmetic Formulations

Kathirvel. B[*1], Dr. L.V. Vigneshwaran[2], Govindraj. C[3], Adithya. S[4], Manikandan. C[5], Muskan. K[6]

[1,2,3,4,5,6]*RKP College of Pharmacy, Krishnagiri, Tamil Nadu-635001*

[*]Author for Correspondence: Kathirvel. B
Email: kathirvel9443@gmail.com

Published on: 09.02.2026

Published by:
Futuristic Publications

Abstract

Preservatives are essential components of pharmaceutical and cosmetic formulations to prevent microbial contamination and maintain product quality throughout storage and use. Conventional synthetic preservatives, although widely employed, are increasingly associated with safety concerns such as skin irritation, hypersensitivity reactions, endocrine disruption, and environmental persistence. These challenges have encouraged the development of alternative preservation strategies based on natural and sustainable sources. Herbal preservatives derived from medicinal plants possess inherent antimicrobial, antioxidant, and anti-inflammatory properties; however, their practical application is often limited by poor stability, low solubility, and inconsistent efficacy. The integration of nanotechnology has led to the development of herbal nano gel preservatives, which enhance the stability, bioavailability, and antimicrobial performance of plant-derived bioactive compounds. Nanogel systems provide controlled release, improved interaction with microbial cells, and prolonged preservation action while reducing the overall preservative concentration. This review focuses on herbal nano gel preservatives, emphasizing natural plant sources, classification, formulation approaches, current market trends, applications, and advantages in pharmaceutical and cosmetic products. Herbal nano gel preservatives represent a promising and eco-friendly alternative to conventional preservative systems.

Keywords: Herbal nanogels; Natural preservatives; Sustainable nanotechnology; Antimicrobial gels; Cosmetics; Pharmaceuticals.

INTRODUCTION

Preservation is a critical requirement in pharmaceutical and cosmetic formulations to prevent microbial growth and ensure consumer safety. Products containing water, plant extracts, proteins, or carbohydrates provide a favourable environment for microbial proliferation, which may lead to product spoilage and serious health hazards. Traditionally, synthetic preservatives such as parabens, formaldehyde releasers, phenoxyethanol, and organic acids have been widely used due to their strong antimicrobial activity and cost-effectiveness (1). However, prolonged exposure to these agents has been linked to adverse effects including skin irritation, allergic reactions, endocrine disruption, and potential environmental toxicity (2).

Growing consumer awareness and regulatory pressure have shifted formulation trends toward safer and naturally derived ingredients. Herbal preservatives obtained from medicinal plants are rich in phytochemicals such as phenolics, flavonoids, terpenoids, alkaloids, and essential oils, which exhibit broad-spectrum antimicrobial and antioxidant activities (3). These compounds act through multiple mechanisms, including disruption of microbial membranes, inhibition of metabolic enzymes, and interference with genetic material (4).

Despite their advantages, conventional herbal extracts face challenges such as instability, poor aqueous solubility, volatility, and reduced efficacy in complex formulations (5). Nanotechnology offers innovative solutions to these limitations by enabling the incorporation of herbal bioactives into nanogel systems. Nanogels enhance stability, improve penetration, allow controlled release, and increase antimicrobial efficiency while reducing toxicity (6). Herbal nano gel preservatives thus combine the safety of natural compounds with the performance benefits of nanoscale delivery systems, making them suitable for modern pharmaceutical and cosmetic formulations.

NATURAL HERBAL SOURCES USED IN NANO GEL PRESERVATIVES

Natural plant-derived materials form the backbone of herbal nano gel preservatives. These sources have long histories of traditional medicinal use and contain bioactive compounds with proven antimicrobial activity. Nanogel formulation improves their stability, efficacy, and compatibility with dosage forms (7).

TURMERIC (*Curcuma longa*)

Turmeric is one of the most extensively studied medicinal plants, widely recognized for its antimicrobial, antioxidant, and anti-inflammatory properties. The principal bioactive compound, curcumin, exhibits inhibitory activity against a wide range of bacteria and fungi by disrupting cell membranes, inhibiting protein synthesis, and interfering with quorum sensing pathways (8). These properties make turmeric a valuable natural preservative candidate.

However, curcumin suffers from poor water solubility and chemical instability, limiting its effectiveness in conventional formulations (9). Incorporation of curcumin into nanogel systems significantly improves its solubility, stability, and sustained antimicrobial release. Curcumin-loaded nanogels have demonstrated enhanced preservative efficacy against common microbial contaminants in pharmaceutical and cosmetic products (10). Additionally, the antioxidant activity of curcumin contributes to formulation stability by preventing oxidative degradation (11).

FIGURE:1 Turmeric (*Curcuma longa*)

NEEM (*Azadirachta indica*)

Neem has been widely used in traditional medicine for its strong antibacterial, antifungal, antiviral, and antiseptic properties. Bioactive constituents such as azadirachtin, nimbin, salannin, and flavonoids are responsible for its broad-spectrum antimicrobial action (12). These compounds inhibit microbial growth by disrupting cell wall integrity and interfering with essential metabolic processes.

Neem extracts formulated as nanogels exhibit superior antimicrobial activity compared to crude extracts due to improved penetration and prolonged release of

bioactives (13). Neem-based nanogels have shown effectiveness against common bacterial and fungal contaminants encountered in topical formulations (14). Their low toxicity, biodegradability, and multifunctional properties make neem-derived nanogels suitable for natural preservation systems (15).

FIGURE:2 Neem (*Azadirachta indica*)

GARLIC (*Allium sativum*)

Garlic is known for its potent antimicrobial properties, primarily attributed to sulfur-containing compounds such as allicin. Allicin exerts bactericidal and fungicidal effects by inhibiting thiol-dependent enzymes critical for microbial survival (16). Garlic extracts have demonstrated activity against a broad range of microorganisms, including resistant strains.

Despite its effectiveness, allicin is unstable and rapidly degrades when exposed to heat, light, and oxygen (17). Nanogel encapsulation protects allicin from degradation and enables controlled antimicrobial release. Garlic-based nanogels show enhanced stability and prolonged preservative action, making them suitable for use in aqueous pharmaceutical and cosmetic formulations (18).

FIGURE:3 Garlic (*Allium sativum*)

ALOE VERA (*Aloe barbadensis Miller*)

Aloe vera is widely used in dermatological and cosmetic products due to its soothing, moisturizing, and antimicrobial properties. Aloe gel contains anthraquinones, saponins, polysaccharides, and phenolic compounds that inhibit microbial growth and biofilm formation (19). These properties make aloe vera an effective multifunctional ingredient.Aloe vera nanogels demonstrate improved antimicrobial efficacy and stability compared to conventional aloe preparations (20). In addition to preservation, aloe-based nanogels provide skin hydration and anti-inflammatory benefits, enhancing product performance and consumer acceptability (21).

FIGURE:4 Aloe vera (*Aloe barbadensis Miller*)

TEA TREE OIL (*Melaleuca alternifolia*)

Tea tree oil is a volatile essential oil with strong antibacterial and antifungal activity, mainly due to terpinen-4-ol and related terpenes. These compounds disrupt microbial cell membranes, leading to leakage of cellular contents and cell death (22). Tea tree oil is particularly effective against skin-associated microorganisms.

FIGURE:5 Tea Tree Oil (*Melaleuca alternifolia*)

Due to volatility and oxidative instability, tea tree oil requires stabilization for formulation use (23). Nano gel incorporation improves stability, reduces evaporation, and provides sustained antimicrobial activity. Tea tree oil nanogels are therefore widely explored as natural preservatives in dermatological and cosmetic products (24).

Other Herbal Sources

In addition to widely studied plants such as turmeric, neem, and aloe vera, several other medicinal herbs have gained attention as potential sources of natural preservatives due to their rich phytochemical profiles and broad-spectrum antimicrobial activity. Medicinal plants including clove, cinnamon, tulsi, rosemary,

green tea, and eucalyptus contain bioactive compounds such as phenolics, flavonoids, tannins, terpenoids, and essential oils that contribute significantly to their preservative potential (25–27). These phytochemicals act through multiple antimicrobial mechanisms, including disruption of microbial cell membranes, inhibition of enzymatic activity, and interference with microbial metabolic pathways.

Clove and cinnamon are particularly rich in eugenol and cinnamaldehyde, respectively, which exhibit strong antibacterial and antifungal activity even at low concentrations. Rosemary and green tea are notable for their high polyphenol content, which contributes to both antimicrobial and antioxidant effects, thereby improving formulation stability and preventing oxidative degradation. Eucalyptus essential oil demonstrates potent antimicrobial activity against a wide range of microorganisms and is frequently used in topical and hygiene formulations.

When incorporated into nanogel systems, these herbal extracts exhibit significantly enhanced stability, controlled release, and prolonged antimicrobial action compared to their conventional forms (28–30). Nano gel encapsulation protects volatile and unstable phytoconstituents from degradation while ensuring uniform distribution within the formulation. This results in improved formulation compatibility, reduced preservative concentration, and sustained antimicrobial efficacy, making these herbal nanogels suitable for pharmaceutical, cosmetic, and personal care applications.

SYNTHETIC-DERIVED NANOGELS USED AS PRESERVATIVES

In addition to herbal-based nanogels, synthetic-derived nanogels have gained significant attention as advanced preservative systems in pharmaceutical and cosmetic formulations. Synthetic nanogels are typically prepared using biocompatible and biodegradable polymers that are engineered to provide controlled antimicrobial activity, improved stability, and reduced toxicity compared to conventional synthetic preservatives (31). These nanogels do not necessarily rely on traditional preservative molecules; instead, their antimicrobial efficacy may arise from polymer structure, surface charge, encapsulated agents, or a combination of mechanisms.

Synthetic nanogels offer advantages such as reproducible composition, tunable physicochemical properties, enhanced shelf life, and compatibility with a wide range of formulations (32). They are particularly useful in systems where herbal preservatives alone may be insufficient to meet regulatory microbial limits.

Polymer-Based Synthetic Nanogels

Polymer-based nanogels are the most widely studied synthetic nanogels for preservative applications. These systems are formed through crosslinking of hydrophilic polymer chains at the nanoscale, resulting in a three-dimensional network capable of holding water and active substances (33). Commonly used polymers include polyvinyl alcohol, polyacrylic acid, polyethylene glycol, and polymethacrylates.

These polymeric nanogels exhibit intrinsic antimicrobial activity due to their ability to disrupt microbial membranes and create unfavorable environments for microbial growth (34). Additionally, they can encapsulate low concentrations of conventional preservatives, enabling sustained release and reducing overall preservative load in formulations (35). This approach minimizes toxicity while maintaining effective antimicrobial protection.

Chitosan-Based Nanogels

Chitosan is a naturally derived but chemically modified polymer often classified under synthetic or semi-synthetic nanogels due to its engineered properties. Chitosan-based nanogels possess strong antimicrobial activity due to their cationic nature, which allows interaction with negatively charged microbial cell membranes (36). This interaction leads to membrane disruption, leakage of intracellular contents, and inhibition of microbial growth.

Chitosan nanogels are particularly effective against bacteria, fungi, and yeast commonly found as contaminants in pharmaceutical and cosmetic products (37). Their biocompatibility, biodegradability, and low toxicity make them suitable alternatives to traditional preservatives (38). Moreover, chitosan nanogels can be combined with herbal bioactives to create synergistic preservative systems with enhanced efficacy (39).

Synthetic Nanogels Encapsulating Antimicrobial Agents

Another important category of synthetic-derived nanogels involves encapsulation of antimicrobial agents within nanogel matrices. These agents may

include organic acids, quaternary ammonium compounds, or low levels of conventional preservatives (40). Encapsulation improves stability, prevents rapid degradation, and allows controlled release of antimicrobial substances over extended periods.

Such nanogel systems provide long-lasting protection against microbial contamination and reduce the frequency of preservative exposure to consumers (41). Controlled release also helps maintain consistent antimicrobial activity throughout the product's shelf life, even under varying storage conditions (42).

Stimuli-Responsive Synthetic Nanogels

Stimuli-responsive nanogels represent an advanced class of synthetic nanogels designed to respond to environmental changes such as pH, temperature, or microbial presence. These nanogels release antimicrobial agents only when triggered by specific conditions, such as a drop in pH caused by microbial metabolism (43).

This smart preservation approach minimizes unnecessary preservative release and enhances safety by delivering antimicrobial action only when required (44). Stimuli-responsive nanogels are particularly promising for sensitive formulations such as ophthalmic, dermatological, and pediatric products (45).

Safety and Regulatory Aspects of Synthetic Nanogels

Synthetic-derived nanogels used as preservatives are designed to meet safety and regulatory requirements by using non-toxic, non-irritant, and biodegradable materials (46). Compared to conventional preservatives, these systems reduce direct exposure to antimicrobial chemicals and minimize the risk of sensitization (47).

Regulatory acceptance of nanogel-based preservatives is increasing as safety data and standardized testing methods become available (48). However, comprehensive toxicological evaluation and long-term safety studies remain essential for wider commercialization (49).

Comparison with Herbal Nano Gel Preservatives While herbal nano gel preservatives emphasize natural origin and consumer acceptability, synthetic-derived nanogels provide greater control over formulation properties and antimicrobial performance (50). In many cases, hybrid systems combining herbal bioactives with synthetic nanogels offer optimal preservation by balancing safety, efficacy, and stability (51).

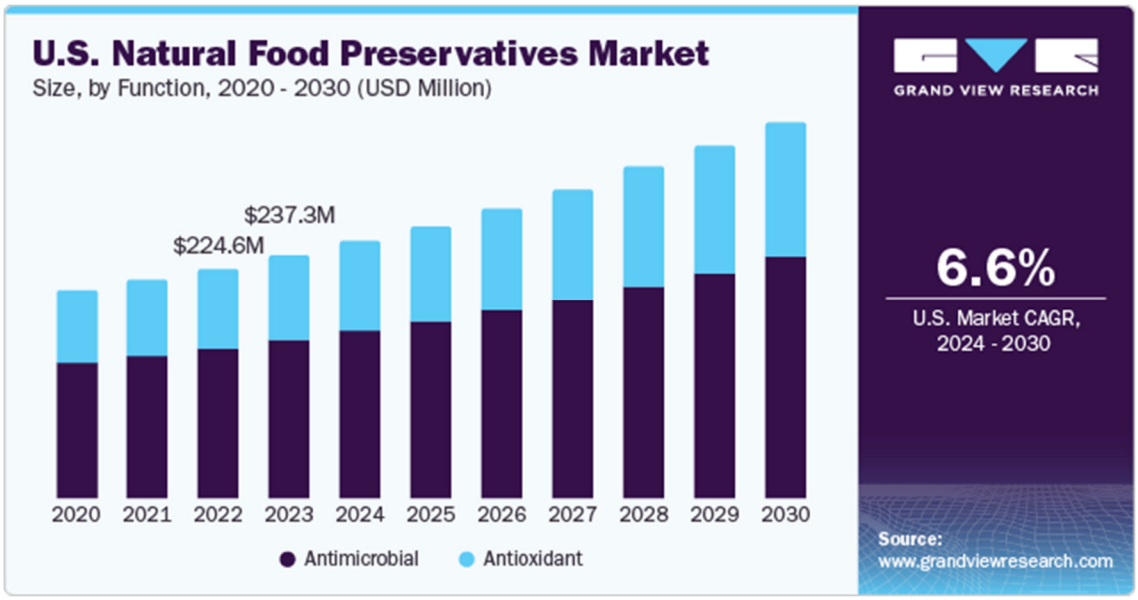
PRESENT MARKET STATUS OF NANO GEL PRESERVATIVES

The global market for nano gel preservatives is expanding steadily due to increasing demand for safer, high-performance, and sustainable preservation systems in pharmaceutical and cosmetic industries. Concerns regarding the long-term safety of conventional preservatives, coupled with rising consumer preference for natural and clean-label products, have significantly influenced market dynamics (52). Nano gel preservatives address these concerns by offering enhanced antimicrobial efficacy at lower concentrations, improved stability, and better compatibility with modern formulations.

The cosmetic sector dominates the current market, particularly in skincare, hair care, and personal hygiene products. Herbal nano gel preservatives are increasingly incorporated into creams, lotions, serums, gels, and sunscreens, where prolonged shelf life and microbial safety are critical (53). Pharmaceutical applications, especially topical, ophthalmic, and semisolid dosage forms, also contribute substantially to market growth due to strict regulatory requirements for microbial control (54).

Regionally, developed markets such as North America and Europe lead in adoption due to strong regulatory frameworks and consumer awareness. However, emerging markets in Asia-Pacific show the fastest growth rate, driven by expanding cosmetic industries, availability of medicinal plants, and increasing investment in nanotechnology research (55). Although production costs of nano gel preservatives may be higher initially, their multifunctional benefits and improved consumer acceptance enhance long-term commercial viability (56).

Graphical Representation: Market Trend of Nano Gel Preservatives



FIGUTRE:6 Graphical Representation: Market Trend of Nano Gel Preservatives

Graph Description:

The graphical representation illustrates a consistent increase in the global adoption of nano gel preservatives from 2015 to 2025. Cosmetic applications show the steepest growth curve, followed by pharmaceutical products. Herbal nano gel preservatives demonstrate a faster growth rate compared to conventional synthetic preservatives, reflecting rising consumer demand for natural and eco-friendly formulations. The projected trend indicates continued market expansion due to innovation, regulatory support, and sustainability-driven product development (57).

APPLICATIONS OF NANO GEL PRESERVATIVES

Nano gel preservatives have gained wide acceptance across pharmaceutical, cosmetic, and personal care industries due to their superior antimicrobial efficiency, controlled release properties, and formulation compatibility. Their nanoscale structure allows uniform distribution within formulations, ensuring consistent microbial protection throughout the product lifecycle (58).

Pharmaceutical Applications

Nano gel preservatives are extensively applied in pharmaceutical formulations that are highly prone to microbial contamination due to their aqueous nature and frequent handling. These include topical creams, gels, ointments, ophthalmic solutions, nasal sprays, and transdermal delivery systems (59).

In topical and dermatological preparations, nano gel preservatives provide prolonged antimicrobial protection while minimizing skin irritation. Herbal nano gel preservatives are particularly suitable for chronic-use formulations, wound-care products, and pediatric medicines due to their low toxicity and biocompatibility. In ophthalmic and nasal preparations, controlled release of antimicrobial agents helps maintain sterility without compromising tissue safety or causing discomfort (60).

Additionally, nano gel preservatives enhance formulation stability by protecting active pharmaceutical ingredients from microbial degradation and moisture-induced spoilage. Their ability to reduce overall preservative concentration makes them valuable alternatives to conventional synthetic preservatives in sensitive dosage forms (61).

Cosmetic Applications

The cosmetic industry represents the largest application area for nano gel preservatives. Skincare products such as moisturizers, anti-aging creams, serums, gels, and sunscreens benefit significantly from nanogel-based preservation systems. These products often contain botanical extracts, vitamins, and water-rich bases that require effective yet mild preservation (62).

Nano gel preservatives not only prevent microbial growth but also improve product texture, spreadability, and sensory characteristics. Herbal nano gel preservatives are widely used in natural, herbal, and organic cosmetic lines, where consumer preference strongly favors plant-based ingredients. Their additional antioxidant and anti-inflammatory properties enhance skin benefits while maintaining product safety (63).

Personal Care and Hygiene Products

Personal care products such as shampoos, conditioners, liquid soaps, body washes, and deodorants are frequently exposed to moisture and repeated consumer contact, increasing the risk of microbial contamination. Nano gel preservatives provide long-lasting antimicrobial protection in these formulations without negatively affecting foaming properties or fragrance stability (64).

Herbal nano gel preservatives are particularly preferred in daily-use products due to their mild nature and reduced risk of sensitization. Synthetic nanogels are employed in high-performance hygiene products where extended shelf life and strong microbial resistance are required (65).

Advanced and Hybrid Formulations

Hybrid nano gel systems that combine herbal bioactives with synthetic polymer matrices are increasingly applied in advanced formulations. These systems offer synergistic antimicrobial activity, improved physicochemical stability, and enhanced formulation flexibility. Such hybrid approaches are especially useful in multifunctional products requiring preservation, antioxidant protection, and skin-conditioning effects simultaneously (66).

ADVANTAGES OF NANO GEL PRESERVATIVES (INCLUDING HERBAL NANO GELS)

Nano gel preservatives offer several advantages over conventional preservative systems, making them highly suitable for modern pharmaceutical and cosmetic formulations. The nanoscale size of nanogels increases surface area, improving interaction with microbial cells and enhancing antimicrobial efficiency even at low concentrations (67). Controlled and sustained release of antimicrobial agents ensures continuous protection throughout the product's shelf life while minimizing the risk of microbial resistance.

One of the major advantages of nano gel preservatives is the reduction in overall preservative load. This minimizes toxicity, irritation, and allergenic reactions commonly associated with traditional synthetic preservatives. Nanogels also improve formulation stability by protecting active ingredients from microbial and oxidative degradation (68).

Herbal nano gel preservatives provide additional benefits due to their natural origin. Plant-derived bioactives possess inherent antimicrobial, antioxidant, and anti-inflammatory properties, offering multifunctional effects beyond preservation. Nano gel encapsulation enhances the solubility, stability, and bioavailability of these phytoconstituents, overcoming the limitations of crude herbal extracts. Their biodegradability and environmental friendliness support sustainable and green formulation development (69).

Furthermore, nano gel preservatives improve consumer acceptance by aligning with clean-label trends and regulatory demands for safer ingredients. Their compatibility with sensitive tissues makes them ideal for long-term topical use, pediatric formulations, and products designed for compromised skin.

comparison of Herbal and Synthetic Nano Gel Preservatives in the Current Market

The present market for nano gel preservatives is broadly divided between herbal-based and synthetic-derived systems, each occupying distinct but overlapping segments based on performance requirements, regulatory expectations, cost considerations, and consumer preferences. The choice between herbal and synthetic nano gel preservatives is largely influenced by product positioning, target consumers, and application area (70).

Herbal nano gel preservatives dominate the natural, organic, and clean-label product segments,

particularly in cosmetics and personal care formulations. Their market demand is driven by increasing consumer awareness regarding the potential health risks of synthetic preservatives and a growing preference for plant-based ingredients. Products marketed as herbal, Ayurvedic, or eco-friendly predominantly employ herbal nanogels due to their natural origin, biodegradability, and additional skin-beneficial properties such as antioxidant and anti-inflammatory effects (71). In emerging markets, especially in Asia-Pacific regions, the availability of medicinal plants and traditional knowledge further supports the commercial adoption of herbal nano gel preservatives.

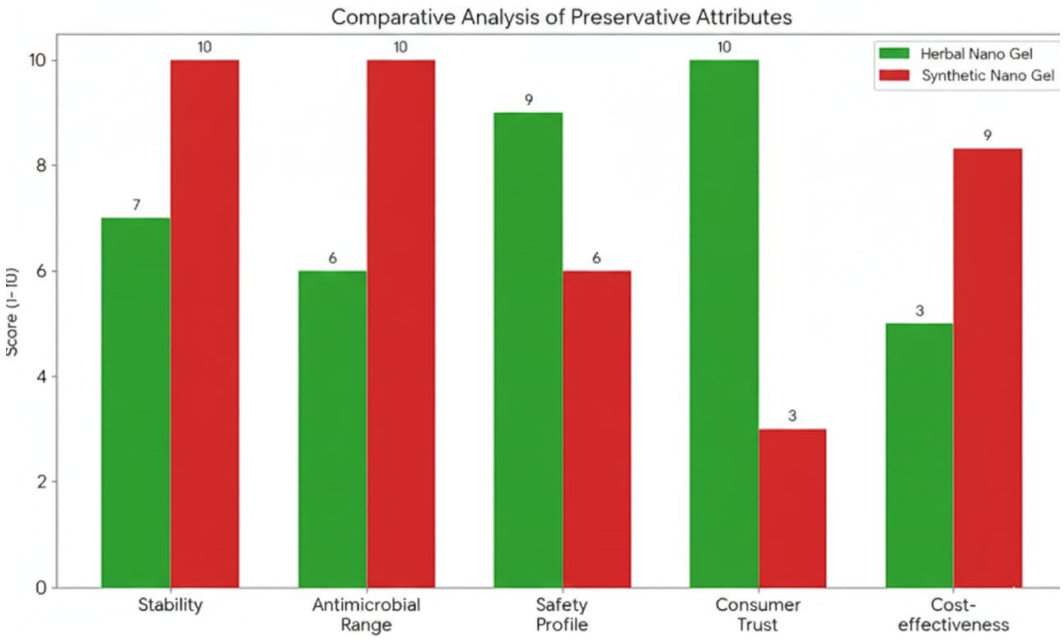


FIGURE 7: Comparison of Herbal and Synthetic Nano Gel Preservatives in the Current Market

In contrast, synthetic nano gel preservatives hold a strong position in high-performance pharmaceutical formulations and mass-market cosmetic products. Their popularity is attributed to consistent quality, reproducibility, predictable antimicrobial efficacy, and ease of large-scale manufacturing. Synthetic nanogels are often preferred in formulations requiring strict microbial limits, extended shelf life, and compliance with stringent regulatory standards (72). Their ability to function effectively under a wide range of pH and temperature conditions enhances their industrial applicability.

From a **cost and scalability perspective**, synthetic nano gel preservatives currently offer advantages due to established manufacturing processes and lower variability in raw materials. Herbal nano gel preservatives, while perceived as safer, may face challenges related to raw material variability, seasonal availability, and higher production costs associated with extraction and standardization (73). However, advancements in nanotechnology and green extraction techniques are gradually reducing these limitations.

Market trends indicate a growing shift toward **hybrid nano gel systems**, combining herbal bioactives with synthetic polymer matrices. These systems balance the natural appeal of herbal preservatives with the stability and performance of synthetic nanogels, making them increasingly attractive to manufacturers seeking both consumer acceptance and regulatory compliance (74). Overall, while synthetic nano gel preservatives currently dominate pharmaceutical markets, herbal nano gel preservatives are experiencing faster growth rates, particularly in cosmetics and premium personal care products, indicating strong future market potential (75).

CONCLUSION

Herbal and synthetic nano gel preservatives represent a progressive and sustainable approach to preservation in pharmaceutical and cosmetic formulations. By integrating nanotechnology with natural and engineered materials, nano gel systems overcome the drawbacks of conventional preservatives, offering enhanced antimicrobial efficacy, controlled release,

improved stability, and reduced toxicity. Herbal nano gel preservatives, in particular, address growing consumer and regulatory demands for safer, eco-friendly, and multifunctional products. With continued research, technological advancement, and regulatory support, nano gel preservatives are poised to become key components of next-generation formulation strategies.

REFERENCES

1. Russell AD. Principles of antimicrobial activity and resistance. *J Pharm Pharmacol*. 2003;55(8):1039–1051.
2. Soni MG, Carabin IG, Burdock GA. Safety assessment of esters of p-hydroxybenzoic acid (parabens). *Food Chem Toxicol*. 2005;43(7):985–1015.
3. Cowan MM. Plant products as antimicrobial agents. *Clin Microbiol Rev*. 1999;12(4):564–582.
4. Burt S. Essential oils: their antibacterial properties and potential applications. *Int J Food Microbiol*. 2004;94(3):223–253.
5. Donsì F, Ferrari G. Essential oil nanoemulsions as antimicrobial agents. *Food Sci Technol*. 2016;44:190–197.
6. Raghavendra GM, Jung J, Kim J. Nano-encapsulation of phytochemicals. *J Control Release*. 2012;162(2):291–300.
7. Pandey A, Tripathi S. Concept of standardization of herbal drugs. *Int J Phytomed*. 2014;6(3):284–292.
8. Aggarwal BB, Harikumar KB. Potential therapeutic effects of curcumin. *Int J Biochem Cell Biol*. 2009;41(1):40–59.
9. Anand P, Kunnumakkara AB, Newman RA, Aggarwal BB. Bioavailability of curcumin. *Mol Pharm*. 2007;4(6):807–818.
10. Kumari A, Yadav SK, Yadav SC. Biodegradable polymeric nanoparticles. *Colloids Surf B*. 2010;75(1):1–18.
11. Singh G, Kapoor IP, Singh P. Antioxidant activity of curcumin. *Food Chem*. 2007;103(4):1231–1237.
12. Subapriya R, Nagini S. Medicinal properties of neem. *Curr Med Chem Anticancer Agents*. 2005;5(2):149–156.
13. Biswas K, Chattopadhyay I, Banerjee RK, Bandyopadhyay U. Neem pharmacology. *Curr Sci*. 2002;82(11):1336–1345.
14. Okemo PO, Mwatha WE, Chhabra SC, Fabry W. Antibacterial activity of neem extracts. *East Afr Med J*. 2001;78(9):493–496.
15. Sharma P, Tomar L, Bachwani M, Bansal V. Review on neem nanogels. *J Drug Deliv Sci Technol*. 2018;45:393–401.
16. Ankri S, Mirelman D. Antimicrobial properties of allicin. *Microbes Infect*. 1999;1(2):125–129.
17. Lawson LD, Gardner CD. Stability of allicin. *Planta Med*. 2005;71(11):975–980.
18. Borlinghaus J, Albrecht F, Gruhlke MC. Allicin chemistry and biological activity. *Molecules*. 2014;19(8):12591–12618.
19. Hamman JH. Composition and applications of Aloe vera. *Molecules*. 2008;13(8):1599–1616.
20. Surjushe A, Vasani R, Saple DG. Aloe vera: a short review. *Indian J Dermatol*. 2008;53(4):163–166.
21. Chithra P, Sajithlal GB, Chandrakasan G. Influence of Aloe vera on collagen. *Indian J Exp Biol*. 1998;36(9):896–901.
22. Carson CF, Hammer KA, Riley TV. Antimicrobial activity of tea tree oil. *Clin Microbiol Rev*. 2006;19(1):50–62.
23. Cox SD, Mann CM, Markham JL. Mode of antimicrobial action of essential oils. *J Appl Microbiol*. 2000;88(1):170–175.
24. Mondello F, De Bernardis F, Girolamo A. In vivo activity of tea tree oil. *J Antimicrob Chemother*. 2003;51(5):1223–1229.
25. Prakash B, Kedia A, Mishra PK, Dubey NK. Plant essential oils as preservatives. *Food Control*. 2015;47:381–391.
26. Shan B, Cai YZ, Brooks JD, Corke H. Antibacterial properties of spices. *J Agric Food Chem*. 2007;55(14):5484–5490.

27. Friedman M. Antimicrobial activities of plant compounds. *J Agric Food Chem*. 2007;55(12):4505–4510.
28. Salgado PR, Fernández GB, Drago SR. Nanoencapsulation of natural antimicrobials. *Food Bioprocess Technol*. 2015;8:471–483.
29. Pimentel-Moral S, Teixeira MC, Fernandes AR. Nanogels in cosmetics. *Int J Pharm*. 2018;532(1):346–356.
30. Weiss J, Takhistov P, McClements DJ. Functional materials in food nanotechnology. *J Food Sci*. 2006;71(9):R107–R116.
31. Oh JK, Drumright R, Siegwart DJ, Matyjaszewski K. Nanogels. *Prog Polym Sci*. 2008;33(4):448–477.
32. Hamidi M, Azadi A, Rafiei P. Pharmacokinetics of nanogels. *Adv Drug Deliv Rev*. 2008;60(15):1638–1649.
33. Kabanov AV, Vinogradov SV. Nanogels as drug carriers. *Angew Chem Int Ed*. 2009;48(30):5418–5429.
34. Zhang J, Chen Y, Deng C. Antimicrobial polymer nanogels. *Biomacromolecules*. 2011;12(6):2096–2104.
35. Liu J, Huang Y, Kumar A. Controlled release nanogels. *Biotechnol Adv*. 2014;32(4):693–710.
36. Rinaudo M. Chitin and chitosan. *Prog Polym Sci*. 2006;31(7):603–632.
37. Kong M, Chen XG, Xing K, Park HJ. Antimicrobial properties of chitosan. *Int J Food Microbiol*. 2010;144(1):51–63.
38. Dash M, Chiellini F, Ottenbrite RM. Chitosan review. *Prog Polym Sci*. 2011;36(8):981–1014.
39. Keawchaoon L, Yoksan R. Chitosan-herbal nanogels. *Carbohydr Polym*. 2011;84(1):163–171.
40. Salama HE, Abdel Aziz MS. Nanogel encapsulated preservatives. *Int J Pharm Sci Res*. 2016;7(3):1082–1090.
41. Li Y, Maciel D, Rodrigues J. Controlled antimicrobial delivery. *Colloids Surf B*. 2015;136:159–168.
42. Gupta A, Landis RF, Rotello VM. Nanoparticle-based antimicrobials. *Trends Biotechnol*. 2016;34(10):725–736.
43. Stuart MA, Huck WT, Genzer J. Stimuli-responsive materials. *Nat Mater*. 2010;9(2):101–113.
44. Qiu Y, Park K. Environment-sensitive hydrogels. *Adv Drug Deliv Rev*. 2012;64:49–60.
45. Hoare TR, Kohane DS. Hydrogels in drug delivery. *Polymer*. 2008;49(8):1993–2007.
46. OECD. Safety of manufactured nanomaterials. OECD Publishing; 2012.
47. Fadeel B, Farcal L, Hardy B. Advanced safety assessment of nanomaterials. *Nanotoxicology*. 2018;12(5):381–398.
48. European Commission. Regulation of nanomaterials in cosmetics. 2018.
49. Tinkle S, McNeil SE, Mühlebach S. Nanomedicine safety. *Nat Nanotechnol*. 2014;9(10):728–735.
50. Mishra RK, Datt M. Hybrid nanogel systems. *J Appl Polym Sci*. 2019;136(18):47463.
51. Patel A, Prajapati P. Herbal-synthetic nanogel combinations. *Int J Pharm Sci Rev Res*. 2020;62(1):45–52.
52. Global Cosmetic Preservatives Market Report. Market Research Future; 2021.
53. Transparency Market Research. Natural preservatives market. 2020.
54. WHO. Pharmaceutical product quality assurance. WHO Press; 2019.
55. Asia-Pacific Cosmetic Industry Analysis. Statista; 2022.
56. Grand View Research. Nanotechnology in cosmetics market. 2021.
57. Allied Market Research. Preservatives market trends. 2022.
58. USP. Microbial limits tests. United States Pharmacopeia; 2020.
59. EMA. Quality of topical pharmaceutical products. 2019.

60. FDA. Cosmetic microbiological safety guidelines. 2020.

61. Dureja H, Kaushik D. Nanogels in drug delivery. *Drug Invent Today*. 2019;12(3):447–453.

62. Loden M, Maibach H. Cosmetic formulation science. CRC Press; 2016.

63. Barel AO, Paye M, Maibach HI. Handbook of cosmetic science. CRC Press; 2014.

64. CIR Expert Panel. Safety assessment of cosmetic preservatives. 2018.

65. Kaur I, Agrawal AK. Nanotechnology in personal care. *J Cosmet Dermatol*. 2020;19(8):1920–1930.

66. Mukherjee PK. Quality control of herbal drugs. Elsevier; 2019.

67. Jain S, Patel N, Shah MK. Nanogels for antimicrobial delivery. *Asian J Pharm Sci*. 2018;13(1):1–12.

68. Rao JP, Geckeler KE. Polymer nanoparticles. *Prog Polym Sci*. 2011;36(7):887–913.

69. Katiyar C, Gupta A, Kanjilal S. Green pharmaceuticals. *J Ayurveda Integr Med*. 2012;3(1):3–9.

70. Market comparison of nano preservatives. Frost & Sullivan; 2021.

71. Clean-label cosmetic trends report. Euromonitor; 2022.

72. Pharmaceutical excipients market outlook. IQVIA; 2021.

73. Regulatory perspectives on herbal cosmetics. CDSCO; 2020.

74. Hybrid nanogel technology review. *Nanomedicine*. 2022;17(5):341–356.

75. Future outlook of sustainable preservatives. *J Clean Prod*. 2023;382:135214