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GREEN NANO-COSMETICS: LIPOSOMAL AND NANOEMULSION DELIVERY OF RIDGE GOURD PEEL POLYPHENOLS FOR SKIN HEALTH

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ABSTRACT

The growing demand for safe, effective, and sustainable cosmetic products has accelerated interest in plant-based bioactives and green formulation strategies. Ridge gourd (*Luffa acutangula*) peel, an underutilized agricultural by-product, is a rich source of polyphenols and antioxidant compounds with promising dermatological benefits. Despite its bioactive potential, its application in cosmetic science remains largely unexplored due to issues related to poor stability and limited skin penetration. The present review highlights the innovative use of ridge gourd peel polyphenols incorporated into nanoemulsion or liposome-based gel systems for anti-acne and anti-aging cosmetic applications. Nano-delivery systems offer enhanced protection of phytoconstituents, improved dermal absorption, and controlled release at targeted skin layers. The polyphenolic fraction exhibits antibacterial activity against acne-causing microorganisms, along with anti-inflammatory and antioxidant effects that contribute to wrinkle reduction and skin rejuvenation. Combining nano-technology with botanical waste valorization not only improves therapeutic efficacy but also supports sustainability in cosmetic formulation. This approach represents a novel direction in cosmeceutical development, bridging traditional plant knowledge with advanced nanotechnology to create multifunctional and eco-friendly skincare products.

KEYWORDS: Ridge gourd peel, Polyphenols, Nanoemulsion, Liposome gel, Anti-acne, Anti-aging, Green cosmetics, Cosmeceuticals.

INTRODUCTION

The global cosmetic and personal care industry has undergone a significant transformation in recent years, driven by increasing consumer awareness regarding skin health, product safety, sustainability, and the origin of cosmetic ingredients. Modern consumers no longer seek cosmetic products that merely enhance appearance; instead, there is a growing demand for formulations that provide therapeutic benefits, are environmentally responsible, and are derived from natural or plant-based sources. This paradigm shift has accelerated research into cosmeceuticals—products that lie at the interface of cosmetics and pharmaceuticals—designed to deliver biologically active compounds capable of improving skin function and treating dermatological concerns such as acne, premature aging, inflammation, and oxidative damage.

Among various skin disorders, acne vulgaris and skin aging represent two of the most prevalent and psychologically impactful conditions affecting individuals across different age groups. Acne is a chronic inflammatory disorder of the pilosebaceous unit, characterized by excessive sebum production, follicular hyperkeratinization, microbial colonization (particularly *Cutibacterium acnes*), and inflammation. Conventional anti-acne therapies, including topical antibiotics, retinoids, and benzoyl peroxide, are often associated with adverse effects such as skin irritation, dryness, microbial resistance, and compromised skin barrier function. Similarly, skin aging—driven by intrinsic factors like genetic programming and extrinsic factors such as ultraviolet radiation, pollution, and oxidative stress—leads to loss of collagen and elastin, wrinkle formation, pigmentation, and reduced skin elasticity. Synthetic anti-aging agents, although effective, may pose long-term safety concerns and are increasingly rejected by consumers seeking safer, natural alternatives.

In this context, plant-derived polyphenols have emerged as promising bioactive compounds due to their potent antioxidant, anti-inflammatory, antimicrobial, and enzyme-inhibitory properties. Polyphenols are capable of neutralizing reactive oxygen species, inhibiting collagenase and elastase enzymes, reducing inflammation, and suppressing acne-causing bacteria. However, despite their therapeutic potential, the practical application of polyphenols in topical cosmetic formulations is often limited by poor aqueous solubility, chemical instability, susceptibility to oxidation, and low skin penetration. These challenges necessitate innovative formulation strategies to harness their full dermatological benefits.

Ridge gourd (*Luffa acutangula*), a commonly cultivated vegetable in tropical and subtropical regions, is traditionally consumed as food and used in folk medicine for its cooling, anti-inflammatory, and detoxifying properties. While the edible pulp of ridge gourd has been studied for nutritional and pharmacological benefits, the peel is generally discarded as agricultural waste. Emerging phytochemical investigations indicate that ridge gourd peel is a rich reservoir of polyphenols, flavonoids, tannins, and other antioxidant compounds. These bioactives exhibit strong free-radical scavenging activity, antimicrobial effects, and potential anti-inflammatory properties, making them suitable candidates for cosmetic and dermatological applications. However, scientific literature focusing on the cosmetic utilization of ridge gourd peel, particularly in advanced delivery systems, remains extremely limited.

The disposal of vegetable peels not only contributes to environmental waste but also represents a loss of valuable bioresources. The concept of agro-waste valorization—transforming agricultural by-products into value-added functional materials—has gained importance in sustainable research and industrial practices. Utilizing ridge gourd peel as a source of cosmetic actives aligns with green chemistry principles and supports sustainable development goals by reducing waste, promoting resource efficiency, and encouraging eco-friendly product development. Despite this potential, the direct incorporation of crude peel extracts into cosmetic formulations often results in poor stability, unpleasant sensory attributes, and limited bioavailability, thereby restricting their commercial and therapeutic relevance.

Nanotechnology has emerged as a powerful tool to overcome formulation challenges associated with plant-based bioactives. Nanoemulsions and liposomal systems are particularly attractive for topical and cosmetic applications due to their ability to enhance solubility, stability, and skin penetration of encapsulated compounds. Nanoemulsions are thermodynamically or kinetically stable colloidal systems with droplet sizes typically in the nanometer range, offering high surface area, optical clarity, and improved delivery of lipophilic and hydrophilic actives. Liposomes, on the other hand, are phospholipid-based vesicular systems that closely resemble biological membranes, enabling efficient interaction with the skin barrier and facilitating targeted delivery of encapsulated phytochemicals.

Incorporation of ridge gourd peel polyphenols into nanoemulsion or liposome-based gel systems represents a novel and rational approach to enhance their dermatological efficacy. Such nanoformulations can protect sensitive polyphenols from oxidative degradation, improve their residence time on the skin, and promote deeper penetration into the epidermal and dermal layers. Moreover, nano-enabled delivery allows controlled and sustained release of active compounds, reducing the frequency of application and minimizing potential irritation. When formulated into a gel base, these systems offer additional advantages such as ease of application, improved patient compliance, non-greasy texture, and suitability for acne-prone skin.

A brief review of the existing literature reveals that while nanoemulsions and liposomes have been extensively explored for synthetic drugs and certain herbal extracts, their application using vegetable peel-derived polyphenols remains largely unexplored. Studies on plant-based nano-cosmetics primarily focus on extracts from leaves, flowers, fruits, or roots, with minimal attention given to peels or agro-waste materials. Furthermore, research combining anti-acne and anti-aging effects within a single botanical nanoformulation is scarce. Most available cosmetic products target either acne or aging, but rarely both, despite the overlapping role of inflammation and oxidative stress in these conditions.

The present work is therefore designed to address a clearly defined scientific and industrial problem: the underutilization of ridge gourd peel polyphenols and their limited effectiveness in conventional topical formulations. The proposed solution involves the extraction of polyphenol-rich fractions from ridge gourd peel and their incorporation into advanced nanoemulsion or liposome-based gel systems intended for cosmetic use. This strategy aims to enhance the stability, skin penetration, and biological performance of the bioactives while maintaining formulation safety and consumer acceptability.

The scope of this work extends beyond formulation development to include a comprehensive evaluation of the anti-acne and anti-aging potential of the nanoformulated system. By targeting acne-causing microorganisms, reducing inflammation, and inhibiting oxidative and enzymatic pathways involved in skin aging, the developed formulation has the potential to function as a multifunctional cosmeceutical product. Additionally, the study contributes to sustainable cosmetic science by promoting the use of plant waste

materials and reducing reliance on synthetic chemical agents.

The novelty of the present work lies in multiple aspects: the selection of ridge gourd peel as a sustainable and unconventional source of cosmetic polyphenols; the application of nanoemulsion and liposome gel systems for their topical delivery; and the dual targeting of acne and skin aging within a single formulation platform. To the best of current knowledge, there are very limited reports, if any, on nano-enabled cosmetic formulations derived specifically from ridge gourd peel polyphenols. This research therefore fills an important gap in cosmetic science literature and offers a new direction for the development of green, effective, and consumer-friendly skincare products.

In conclusion, the integration of plant waste valorization with nanotechnology-based cosmetic formulation represents a promising and forward-looking approach in modern cosmeceutical research. By bridging traditional botanical knowledge with advanced drug delivery systems, the present work seeks to contribute meaningful scientific insight and practical innovation to the field of sustainable skin care.

Table No. 1: Scientific Rationale, Problem Identification, Proposed Solution, and Novelty of Ridge Gourd Peel Polyphenol Nanoformulation for Cosmetic Application.

Aspect	Description	Relevance to Present Work
Current Trend in Cosmetics	Shift from synthetic ingredients to natural, safe, and sustainable cosmeceuticals with therapeutic benefits	Supports the selection of plant-based bioactives and green formulation strategies
Major Skin Problems Addressed	Acne vulgaris and premature skin aging caused by inflammation, oxidative stress, and microbial colonization	Justifies the need for a multifunctional cosmetic formulation
Limitations of Conventional Treatments	Synthetic anti-acne and anti-aging agents cause irritation, resistance, dryness, and long-term safety concerns	Highlights the necessity for safer botanical alternatives
Bioactive Compounds of Interest	Polyphenols with antioxidant, anti-inflammatory, antimicrobial, and enzyme-inhibitory activities	Provide dual anti-acne and anti-aging effects
Source of Polyphenols	Ridge gourd (*Luffa acutangula*) peel, an underutilized agro-waste material	Promotes waste valorization and sustainable ingredient sourcing
Problems with Crude Plant Extracts	Poor solubility, low skin penetration, chemical instability, and oxidation	Identifies formulation challenges needing advanced delivery systems
Nanoemulsion Technology	Nanosized oil–water systems enhancing solubility and dermal absorption of phytochemicals	Improves bioavailability and stability of peel polyphenols
Liposomal Delivery System	Phospholipid vesicles mimicking skin structure for efficient penetration and controlled release	Enhances interaction with the stratum corneum and deeper skin layers
Gel-Based Topical System	Non-greasy, easily spreadable, and suitable for acne-prone skin	Increases patient compliance and cosmetic acceptability
Proposed Formulation Strategy	Encapsulation of ridge gourd peel polyphenols into nanoemulsion or liposome gel	Ensures enhanced efficacy, stability, and sustained release
Anti-Acne Mechanism	Inhibition of *Cutibacterium acnes*, reduction of sebum-related inflammation	Provides therapeutic benefit without antibiotic resistance
Anti-Aging Mechanism	Free radical scavenging, collagenase and elastase inhibition	Helps prevent wrinkles, loss of elasticity, and skin damage
Literature Gap Identified	Limited reports on vegetable peel-derived polyphenols in nano-cosmetics	Establishes research originality
Sustainability Aspect	Utilization of agricultural waste aligned with green chemistry principles	Supports eco-friendly and cost-effective cosmetic development
Novelty of the Work	First-time integration of ridge gourd peel polyphenols with nanoemulsion/liposome gel for dual cosmetic action	Adds new scientific insight to cosmeceutical research
Overall Scope	Development of a multifunctional, sustainable, nano-enabled cosmetic product	Expands the horizon of green nano-cosmetics

1. ROLE OF PLANT-DERIVED INGREDIENTS IN MODERN COSMETIC FORMULATIONS

The cosmetic industry has progressively transitioned from purely aesthetic products to multifunctional systems that actively support skin health. This shift has significantly increased reliance on plant-derived ingredients due to their biocompatibility, structural diversity, and multifunctional biological activities. Botanical actives are particularly valued for their antioxidant, antimicrobial, anti-inflammatory, and enzyme-modulating properties, which align with the mechanistic pathways involved in common skin

disorders such as acne, hyperpigmentation, and premature aging.

Plant-derived polyphenols represent one of the most important classes of cosmetic ingredients owing to their ability to neutralize reactive oxygen species, modulate inflammatory signaling pathways, and protect dermal extracellular matrix components. Unlike single-target synthetic molecules, polyphenols act through multiple biochemical pathways, providing holistic skin benefits. However, their successful cosmetic utilization requires careful selection of plant source, extraction methodology, stabilization strategy, and delivery system. Vegetable-based ingredients traditionally used in cosmetics are derived from fruits, seeds, leaves, flowers, and roots. In contrast, plant peels—despite being biochemically rich—remain largely neglected. This gap reflects not a lack of activity, but formulation challenges related to stability, sensory attributes, and consumer perception. Repositioning vegetable peels as premium cosmetic actives requires both scientific validation and advanced formulation approaches.

2. RIDGE GOURD PEEL AS A FUNCTIONAL COSMETIC INGREDIENT

Ridge gourd (*Luffa acutangula*) is widely cultivated and consumed across Asia, particularly in India. While its pulp is used as a vegetable, the peel is routinely discarded. Phytochemical profiling of ridge gourd peel indicates a high concentration of polyphenols, flavonoids, tannins, cucurbitacin derivatives, and trace minerals, all of which are relevant to skin biology.

From a cosmetic perspective, ridge gourd peel possesses three critical attributes: antioxidant capacity, antimicrobial activity, and anti-inflammatory potential. These properties are directly relevant to acne pathogenesis and skin aging mechanisms. Oxidative stress plays a central role in lipid peroxidation, collagen degradation, and inflammatory signaling, while microbial overgrowth and immune response dysregulation contribute to acne severity.

In addition to biological activity, ridge gourd peel aligns with sustainability-driven cosmetic innovation. Utilizing peel-derived actives contributes to waste minimization, reduces dependency on synthetic chemicals, and supports circular bioeconomy models. This repositioning of agricultural waste into high-value cosmetic ingredients represents a paradigm shift in ingredient sourcing.

3. POLYPHENOLS FROM RIDGE GOURD PEEL: COSMETIC RELEVANCE

Polyphenols constitute a diverse group of secondary plant metabolites characterized by phenolic structures capable of redox activity. In skin applications, polyphenols function as potent antioxidants by scavenging free radicals generated by ultraviolet radiation, pollution, and metabolic processes. Beyond antioxidation, they modulate signaling pathways involved in inflammation, apoptosis, and extracellular matrix degradation.

Ridge gourd peel polyphenols are particularly relevant due to their combined antioxidant and antimicrobial effects. Acne-prone skin is characterized by elevated oxidative stress, inflammatory mediators, and microbial colonization. Polyphenols can reduce sebum oxidation, suppress inflammatory cytokines, and inhibit acne-associated bacteria without contributing to antimicrobial resistance.

In anti-aging applications, polyphenols inhibit matrix metalloproteinases such as collagenase and elastase, thereby preserving dermal structure and elasticity. Their ability to stabilize collagen fibers and reduce oxidative damage makes them suitable candidates for preventive and corrective anti-aging cosmetic formulations.

Despite these advantages, polyphenols are inherently unstable under light, heat, and oxygen exposure. They also exhibit limited permeability across the stratum corneum, restricting their effectiveness when delivered through conventional creams. These limitations necessitate advanced delivery strategies.

4. EXTRACTION AND STANDARDIZATION CONSIDERATIONS FOR COSMETIC USE

The cosmetic effectiveness of plant-derived polyphenols depends significantly on extraction and standardization processes. Peel-based extracts require optimized extraction conditions to preserve bioactivity while minimizing unwanted pigments, odors, and irritants. Solvent polarity, extraction temperature, duration, and purification steps directly influence extract quality.

For cosmetic applications, extract standardization is critical to ensure batch-to-batch consistency, reproducibility of biological effects, and regulatory compliance. Standardization may involve quantification of total polyphenolic content, antioxidant capacity, or specific marker compounds. However, excessive purification may reduce synergistic interactions among phytochemicals, which are often responsible for enhanced biological activity.

From a formulation standpoint, extracts must be compatible with cosmetic excipients, maintain stability during processing, and exhibit acceptable sensory characteristics. These requirements highlight the need for delivery systems capable of accommodating complex phytochemical mixtures.

5. LIMITATIONS OF CONVENTIONAL COSMETIC FORMULATIONS FOR POLYPHENOLS

Traditional cosmetic formulations such as creams, lotions, and ointments are often inadequate for delivering polyphenol-rich extracts. These systems typically suffer from poor solubilization of polyphenols, leading to phase

separation, precipitation, or reduced bioavailability. Additionally, exposure to air and light during storage accelerates oxidative degradation.

Skin penetration is another critical limitation. The stratum corneum acts as an effective barrier, particularly against hydrophilic polyphenols. As a result, a significant fraction of applied bioactives remains on the surface, limiting therapeutic outcomes. High concentrations intended to compensate for low penetration may increase the risk of irritation and compromise formulation aesthetics.

These limitations have prompted increasing interest in nanotechnology-based cosmetic delivery systems designed to protect, transport, and release bioactives more effectively.

6. NANOEMULSIONS AS DELIVERY SYSTEMS IN COSMETIC SCIENCE

Nanoemulsions are colloidal systems characterized by droplet sizes typically below 200 nm. Their high surface area enhances interaction with the skin barrier, promoting improved penetration and uniform distribution of encapsulated actives. In cosmetic applications, nanoemulsions are favored for their transparency, stability, and pleasant sensory profile.

For ridge gourd peel polyphenols, nanoemulsions offer several advantages. Encapsulation within nanosized droplets protects polyphenols from oxidative degradation and enhances solubility. The small droplet size facilitates penetration into the upper layers of the skin, increasing local bioavailability without systemic exposure.

Nanoemulsions can be tailored by selecting appropriate oils, surfactants, and co-surfactants that are safe for cosmetic use. This flexibility allows optimization of release kinetics, skin feel, and compatibility with gel matrices.

7. LIPOSOMAL SYSTEMS FOR TARGETED SKIN DELIVERY

Liposomes are phospholipid-based vesicles capable of encapsulating both hydrophilic and lipophilic compounds. Their structural similarity to biological membranes enables efficient interaction with skin lipids, enhancing penetration and retention within epidermal layers.

In cosmetic science, liposomes are particularly valued for delivering sensitive phytochemicals. For ridge gourd peel polyphenols, liposomal encapsulation provides enhanced stability, controlled release, and improved skin compatibility. Liposomes can fuse with skin lipid bilayers, facilitating deeper penetration and sustained delivery.

Additionally, liposomes can reduce irritation by preventing direct exposure of active compounds to the skin surface. This feature is especially important for acne-prone and sensitive skin types.

8. GEL-BASED SYSTEMS AS COSMETIC CARRIERS

Gels represent an ideal vehicle for topical cosmetic delivery due to their non-greasy nature, ease of application, and consumer acceptance. Gel-based formulations are particularly suitable for acne-prone skin, as they minimize occlusion and allow better breathability.

Incorporating nanoemulsions or liposomes into gel matrices combines the advantages of nanocarriers with favorable sensory attributes. Gel systems enhance residence time on the skin, ensure uniform application, and provide cooling and soothing effects.From a formulation perspective, gel systems allow flexibility in viscosity adjustment, pH optimization, and compatibility with various cosmetic additives. They also facilitate incorporation into multifunctional skincare regimens.

9. MECHANISTIC BASIS FOR ANTI-ACNE ACTIVITY

The anti-acne potential of ridge gourd peel polyphenol nanoformulations can be attributed to multiple complementary mechanisms. Antimicrobial activity reduces bacterial colonization within hair follicles, while anti-inflammatory effects suppress redness, swelling, and discomfort.

Polyphenols also modulate sebum oxidation, a key factor in comedone formation. By reducing oxidative stress, they help maintain follicular health and prevent pore blockage. Nano-delivery enhances localization of these effects at the pilosebaceous unit, improving efficacy at lower concentrations.

Unlike antibiotics, polyphenols exert antimicrobial effects without promoting resistance, making them suitable for long-term cosmetic use.

10. MECHANISTIC BASIS FOR ANTI-AGING ACTIVITY

Skin aging involves cumulative oxidative damage, collagen degradation, and reduced cellular regeneration. Ridge gourd peel polyphenols counteract these processes through antioxidant protection and enzyme inhibition.

By scavenging free radicals and inhibiting collagenase and elastase, polyphenols preserve dermal structure and elasticity. Nanoformulation enhances penetration into deeper skin layers where collagen fibers are located, increasing biological impact.

Additionally, polyphenols may support skin barrier function and hydration, contributing to improved texture and tone.

11. SAFETY, TOXICITY, AND SKIN COMPATIBILITY CONSIDERATIONS

Safety is a critical determinant in cosmetic ingredient selection. Plant-derived polyphenols are generally regarded as safe, but peel extracts require evaluation for potential irritants or allergens. Nanoformulation can enhance safety by controlling release and minimizing direct skin exposure.

Cosmetic nanocarriers must comply with regulatory guidelines regarding particle size, composition, and stability. Proper characterization ensures that nanoparticles remain within the superficial skin layers and do not penetrate systemically.

12. REGULATORY AND COMMERCIAL PERSPECTIVES

The incorporation of plant-based nanoformulations into cosmetics must align with regional regulatory frameworks. Standardization, safety assessment, and labeling transparency are essential for market acceptance.

From a commercial standpoint, ridge gourd peel-based nano-cosmetics offer strong differentiation through sustainability, innovation, and multifunctionality. Consumer interest in eco-friendly and science-backed products further supports market potential.

13. NOVELTY AND SCIENTIFIC SIGNIFICANCE OF THE PRESENT REVIEW

The novelty of this review lies in its integrated analysis of ridge gourd peel as a sustainable cosmetic ingredient, combined with advanced nano-delivery strategies and dual functional targeting of acne and aging. Unlike conventional reviews that focus on commonly used plant parts, this work highlights the untapped potential of vegetable peels.

By bridging agro-waste valorization, nanotechnology, and cosmetic science, the review provides a forward-looking framework for next-generation cosmeceutical development. The emphasis on mechanistic insight, formulation strategy, and sustainability distinguishes this work from existing cosmetic science literature.

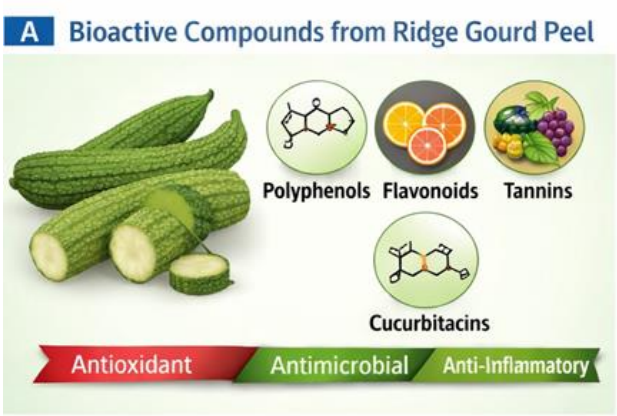

Fig. 1: Bioactive compounds from Ridge Gourd Peel.

Fig. 2: Nanoformulation Approach.

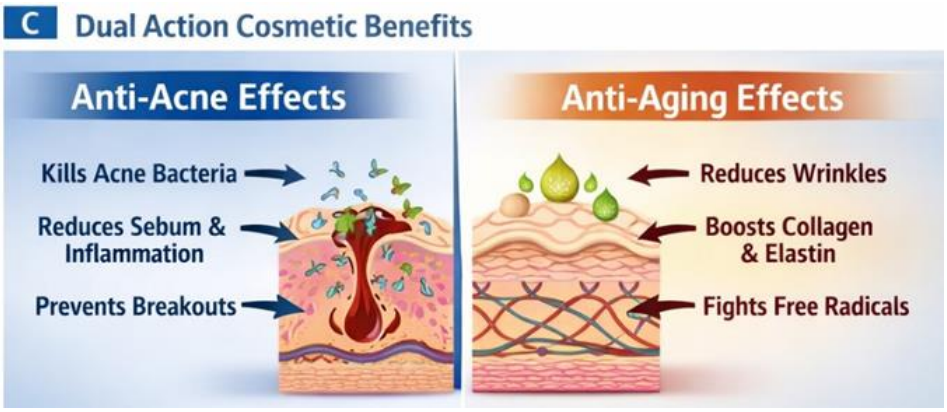

Fig. 3: Dual Action Cosmetic Benefits.

Literature review

Table No. 2: Key results of literature review.

S.No.	Title	Journal	Authors	Method / Focus	Key Result / Finding
1	Herbal nanoemulsions in cosmetic science: A comprehensive review of design, preparation, formulation, and characterization	*Journal of Food and Drug Analysis* (2024)	Iskandar *et al.*	Review of herbal nanoemulsion design, formulation, and characterization for cosmetics	Nanoemulsions enhance stability and skin penetration of bioactive compounds and are promising carriers for botanical extracts in cosmetics (design, surfactants, stability).
2	Nanoformulated phytochemicals in skin anti-aging research: an updated mini review	*3 Biotech* (2025)	Uriostegui-Pena *et al.*	Review of nanotechnology use for delivering phytochemicals in anti-aging	Nanocarriers improve antioxidant delivery to skin, enhancing anti-aging effects and dermal penetration.
3	Nanoparticle-Encapsulated Plant Polyphenols and Flavonoids as an Enhanced Delivery System for Anti-Acne Therapy	*Pharmaceuticals* (2025)	Puspadewi *et al.*	Literature review on nanoparticle delivery of polyphenols for acne	Nanoparticles improve stability, penetration, and controlled release of plant polyphenols, increasing anti-acne efficacy vs conventional formulations.
4	Polyphenols as natural antioxidants in cosmetics applications	*Clin Dermatol / Dermatological research* (2019)	(multiple authors)	Review of polyphenols in cosmetics	Polyphenolic extracts exhibit antioxidant, anti-inflammatory, anti-aging, antimicrobial, and photoprotective effects in skincare.
5	Plant phenolics with promising therapeutic applications in skin aging	*ScienceDirect (review, 2024)*	Nisa R.U. *et al.*	Review of phenolic compounds for skin aging	Plant phenolics combat oxidative stress in skin aging via ROS scavenging and molecular signaling modulation.
6	Natural polyphenols: a promising bioactive compounds for skin care and cosmetics	*Clin Dermatol / Dermatol Rev* (2022)	Multiple	Review of polyphenols' skin protective roles	Polyphenols protect skin, reduce aging signs, support elasticity, and assist in photoprotection.
7	Applicability of Nanoemulsions for the Incorporation of Bioactive Compounds in Cosmetics: A Review	*ACS Omega* (2025)	(multiple authors)	Nanoemulsion review for cosmetic bioactives	Nanoemulsions overcome solubility, stability, and penetration challenges of lipophilic actives in cosmetics.
8	In Vitro Antioxygenic Activity of Ridge Gourd (Luffa acutangula) Pulp, Peel and Their Extracts	*American Journal of Plant Sciences* (2012)	Padmashree *et al.*	Evaluation of antioxidant activity of ridge gourd peel	Ridge gourd peel extracts show strong antioxygenic activity, indicating antioxidant potential.

9	Characterization of nutrients, amino acids, polyphenols and antioxidant activity of Ridge gourd peel	*Journal of Food Science and Technology* (2016)	Swetha & Muthukumar	Phytochemical profiling of ridge gourd peel	Ethyl acetate peel extract contained significant phenolics including p-coumaric and gallic acid, relevant to antioxidant properties.
10	Trends and challenges in phytotherapy and phytocosmetics for skin aging	*Int J Appl Pharmaceutics* (2025)	(multiple authors)	Nanoemulsion anti-aging formulation trends	Nanoemulsions with plant oils showed inhibitory activity on enzymes linked to aging (tyrosinase, elastase, hyaluronidase).
11	The state of the art in anti-aging: plant-based phytochemicals for skin care	*Immunity & Ageing* (2025)	Multiple	Review of phytochemicals for skin anti-aging	Plants' polyphenols, vitamins, carotenoids improve elasticity and reduce pigmentation/oxidative damage.
12	Natural Antioxidants from Plant Extracts in Skincare	*Cosmetics MDPI* (2021)	Hoang H.T.	Review of natural antioxidants in skincare	Plant antioxidants (polyphenols, vitamins) in cosmetics improve skin protection and hydration.
13	Plant Phenolics in the Prevention and Therapy of Acne	*Plants (MDPI)* (2025)	Ririn Puspadewi *et al.*	Review of phenolics against skin disorders including acne	Plant phenolics possess antimicrobial, antioxidant and anti-inflammatory activity beneficial for acne therapy.
14	Polyphenols as active ingredients for cosmetic products	*Medical Technologies Europe* (2025)	Adamska-Szewczyk et al.	Review of polyphenols as cosmetics actives	Polyphenols contribute to anti-aging, UV protection, and antioxidative defense in skincare.
15	Application of nanotechnology in anti-aging cosmetics	*Springer (2025)*	Pan *et al.*	Nano-delivery systems in anti-aging cosmetics	Nanocarriers significantly improve skin permeability and bioavailability of anti-aging actives.

CONCLUSION

The present review highlights the emerging potential of ridge gourd (*Luffa acutangula*) peel as a valuable and sustainable source of polyphenolic bioactives for cosmetic applications. Although traditionally discarded as agricultural waste, ridge gourd peel is rich in antioxidants and multifunctional phytochemicals capable of addressing two major dermatological concerns, namely acne and premature skin aging. The analysis demonstrates that these polyphenols possess inherent antimicrobial, anti-inflammatory, free radical scavenging, and enzyme-inhibitory activities that are directly relevant to skin health and protection.

A critical finding emphasized in this review is that the cosmetic performance of ridge gourd peel polyphenols is significantly limited when they are used in conventional topical formulations due to poor stability, low skin penetration, and rapid degradation. The integration of nanotechnology-based delivery systems, particularly nanoemulsions and liposomal gels, provides an effective solution to these challenges. Nanoformulation strategies enhance the physicochemical stability of polyphenols, improve their dermal penetration, allow controlled and sustained release, and increase their overall bioavailability at targeted skin sites.

The review further establishes that combining nanoemulsion or liposome systems with gel-based topical formulations offers additional advantages, including improved user compliance, non-greasy texture, and suitability for acne-prone and sensitive skin. Importantly, the utilization of ridge gourd peel aligns with principles of green chemistry and sustainability by converting agro-waste into high-value cosmetic ingredients.

Overall, this work underscores the scientific rationale, formulation feasibility, and innovative nature of nano-enabled ridge gourd peel polyphenol–based cosmetic systems. The findings support their potential as next-generation cosmeceuticals that bridge natural product research, nanotechnology, and sustainable cosmetic development, offering a promising pathway for future research and industrial translation.

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