

NANO-COSMECEUTICAL DELIVERY OF *MORINGA* POD PEEL PHYTOCHEMICALS
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ABSTRACT

Moringa oleifera is widely recognized for its nutritional and medicinal value, yet the cosmetic potential of its pod peel remains largely underutilized. The pod peel, commonly discarded as vegetable waste, is a rich source of polyphenols, flavonoids, tannins, and other bioactive compounds with significant antioxidant, anti-inflammatory, and antimicrobial properties. These phytochemicals show promising applications in skin protection, particularly against oxidative stress, premature aging, acne-related infections, and environmental pollution-induced damage. However, the direct use of plant extracts in topical formulations is often limited by poor stability, low skin penetration, and reduced bioavailability. Nano-cosmeceutical delivery systems such as nanoemulsions, liposomes, solid lipid nanoparticles, and polymeric nanocarriers offer innovative strategies to enhance the efficacy of moringa pod peel-derived actives. Encapsulation of these phytoconstituents can improve controlled release, deeper dermal absorption, and long-term formulation stability, leading to more effective skincare products. This review highlights the phytochemical profile of moringa pod peel, its dermatological benefits, and recent advances in nanotechnology-based cosmetic delivery approaches. The sustainable utilization of moringa pod peel in nano-cosmeceuticals may open new opportunities for developing eco-friendly, high-value skincare formulations.

KEYWORDS: *Moringa oleifera* pod peel; nano-cosmeceuticals; phytochemicals; antioxidant activity; skin protection; nanoemulsion; anti-aging; sustainable cosmetics.

INTRODUCTION

Moringa oleifera, commonly known as drumstick or horseradish tree, is a fast-growing, drought-resistant plant widely cultivated across tropical and subtropical regions. Traditionally, it has been recognized for its nutritional, medicinal, and therapeutic properties. While substantial research has focused on the leaves, seeds, and flowers of *Moringa* for their antioxidant, anti-inflammatory, and antimicrobial activities, the pod peel, which constitutes a significant portion of vegetable waste, has received comparatively less attention. The outer peel of *Moringa* pods, often discarded during culinary use, is a rich repository of bioactive compounds including polyphenols, flavonoids, tannins, saponins, carotenoids, and vitamins. These phytochemicals are known to provide antioxidant protection, regulate inflammatory responses, and combat microbial infections, all of which are critical for maintaining

healthy skin. Despite its potential, the direct application of *Moringa* pod peel extracts in topical formulations faces limitations due to poor stability, low bioavailability, and restricted penetration through the stratum corneum, the primary barrier of the skin.

The increasing prevalence of skin disorders such as premature aging, acne, hyperpigmentation, and oxidative stress-induced damage, largely driven by environmental pollutants, ultraviolet radiation, and lifestyle factors, has created a pressing demand for effective, safe, and sustainable cosmetic solutions. Conventional synthetic ingredients in skincare formulations often provide immediate effects but are associated with long-term side effects, including irritation, sensitization, and environmental harm. This underscores the urgent need for novel, plant-based cosmeceutical approaches that combine efficacy, safety, and sustainability. *Moringa* pod

peel, as an underutilized natural resource, offers an ideal solution by converting agricultural waste into a high-value cosmetic ingredient, thereby aligning with principles of green chemistry and circular economy.

Recent advances in nanotechnology have revolutionized the field of cosmetic science by enabling the development of nano-cosmeceutical delivery systems. Nanoemulsions, liposomes, solid lipid nanoparticles, and polymeric nanocarriers have demonstrated significant potential in enhancing the stability, solubility, bioavailability, and controlled release of plant-derived bioactives. These delivery platforms facilitate deeper penetration into the dermal layers, ensuring that the phytochemicals exert their protective and therapeutic effects more efficiently. Nanoformulations also improve the shelf-life and aesthetic properties of skincare products, including texture, spreadability, and non-greasy feel, which are essential for consumer acceptance. By incorporating Moringa pod peel extracts into nano-cosmeceutical systems, it is possible to develop advanced skincare products that not only provide antioxidant and anti-aging benefits but also target pollution-induced skin damage and microbial challenges.

A comprehensive review of existing literature reveals that most studies on *Moringa oleifera* have predominantly focused on leaves and seed-derived compounds. For instance, Moringa leaf extracts have been widely reported to possess significant antioxidant and anti-inflammatory activities suitable for dermatological applications. Similarly, Moringa seed oil has demonstrated moisturizing, anti-aging, and antimicrobial properties. However, studies specifically targeting Moringa pod peel phytochemicals for cosmeceutical use remain sparse. A few preliminary investigations indicate the presence of flavonoids, tannins, and phenolic compounds in the pod peel, which suggests potential for anti-aging, anti-acne, and skin-protective applications. Yet, systematic studies involving extraction optimization, characterization of bioactive compounds, formulation development, and evaluation of dermal efficacy are lacking. This research gap highlights the novelty and importance of investigating Moringa pod peel as a sustainable, underexplored source of cosmeceutical ingredients.

The proposed study aims to address this gap by evaluating the phytochemical composition of Moringa pod peel, assessing its dermatological potential, and exploring advanced nano-cosmeceutical delivery systems for enhanced skin protection. By employing green extraction methods, such as hydroalcoholic, ultrasound-assisted, and microwave-assisted extraction, the bioactive compounds can be efficiently recovered while minimizing solvent use and environmental impact. Subsequent formulation into nanoemulsions or liposomal systems can improve skin penetration, controlled release, and overall efficacy of the actives. Furthermore, comprehensive *in vitro* studies, including antioxidant

assays, anti-inflammatory tests, tyrosinase inhibition, and antimicrobial evaluations, can provide robust evidence of the therapeutic and cosmetic potential of the extract.

The scope of this work extends beyond mere cosmetic application. By valorizing vegetable waste into high-value cosmeceutical ingredients, the study contributes to sustainability and environmental conservation. It demonstrates an innovative approach to reduce agro-industrial waste while creating economically viable and eco-friendly products. Additionally, by integrating nanotechnology, the research aligns with current trends in precision cosmeceuticals, offering advanced formulations that meet both consumer demands and regulatory standards. This approach is particularly relevant in urban environments, where exposure to pollution, UV radiation, and oxidative stress is increasingly associated with premature skin aging and dermatological disorders.

The novelty of this research lies in its focus on an underexplored natural source—Moringa pod peel—combined with modern nano-delivery systems. Unlike conventional plant-based cosmetics, which often use leaves or seeds, this work emphasizes the valorization of waste, thereby contributing to sustainability and cost-effectiveness. Moreover, the integration of nanotechnology ensures enhanced bioavailability and efficacy, positioning the study at the forefront of advanced cosmeceutical development. The anticipated outcomes include the identification of potent skin-protective phytochemicals, development of stable and effective nano-formulations, and provision of a sustainable model for converting agricultural waste into high-value cosmetic products.

In summary, the proposed study addresses a critical gap in cosmetic research by exploring the potential of Moringa pod peel as a nano-cosmeceutical ingredient. It combines traditional knowledge of Moringa's therapeutic properties with modern technological approaches to overcome limitations related to stability, penetration, and bioavailability. The work contributes to multiple domains, including sustainable agriculture, green chemistry, dermatology, and cosmetic science. By transforming underutilized vegetable peel into advanced skincare solutions, this research has the potential to offer safe, effective, and environmentally responsible alternatives to conventional cosmetic products. Such an approach not only enhances human skin health but also promotes a circular economy and innovation in cosmeceutical.

Table no. 1: phytochemicals identified in Moringa pod peel development.

Phytochemical	Presence in Pod Peel	Cosmetic Relevance	Mechanism / Effect
Polyphenols	High	Anti-aging, antioxidant	Free radical scavenging, prevention of collagen degradation
Flavonoids (Quercetin, Kaempferol)	Moderate-High	Skin brightening, anti-inflammatory	Tyrosinase inhibition, reduces oxidative stress
Tannins	Moderate	Skin tightening, pore minimization	Protein precipitation, antioxidant activity
Saponins	Low-Moderate	Natural cleanser, foaming agent	Surfactant properties, antimicrobial effect
Vitamin C	Low	Collagen synthesis, anti-wrinkle	Stimulates fibroblast activity, reduces pigmentation
Carotenoids	Low	UV protection, skin rejuvenation	Absorbs UV radiation, antioxidant effect
Antimicrobial compounds	Moderate	Anti-acne, skin hygiene	Inhibits <i>S. aureus</i> and <i>P. acnes</i> growth

Table no. 2: Nanoformulation Approaches for Moringa Pod Peel.

Nano-Delivery System	Advantages	Relevant Cosmetic Application
Nanoemulsion	High solubility, improved skin penetration, controlled release	Anti-aging serum, sunscreen booster
Liposomes	Biocompatible, protects sensitive phytochemicals	Moisturizers, anti-pigmentation creams
Solid Lipid Nanoparticles (SLN)	Enhanced stability, sustained release	Anti-acne gels, anti-inflammatory creams
Polymeric Nanoparticles	Targeted delivery, high loading capacity	Anti-aging and anti-pollution creams
Nanogel / Hydrogel Formulations	Hydration, controlled release, non-irritating	Soothing face masks, moisturizing gels

1. Botanical Source and Raw Material Characteristics

Moringa oleifera Lam. belongs to the family Moringaceae and is cultivated extensively in tropical climates. The immature pods are consumed as a vegetable, while the outer fibrous peel of the pod is normally discarded during cooking. This peel constitutes nearly 28–35% of the total pod mass and therefore represents a significant agro-waste resource. Unlike the leaves and seeds, which have been repeatedly explored for nutraceutical and medicinal applications, the pod peel remains poorly utilized despite its complex chemical composition.

The peel is structurally composed of a protective epidermal layer, sub-epidermal parenchyma tissue, and fibrous vascular strands. These tissues contain concentrated secondary metabolites because the peel functions biologically as a defensive barrier against insects, microbial invasion, and environmental stress. Plants typically accumulate phenolic compounds in external tissues for protection against ultraviolet radiation and oxidative injury, making peel material particularly rich in skin-protective molecules.

Fresh peels exhibit high moisture content (approximately 70–75%), moderate fiber content, and a notable fraction of phenolic and lipid-soluble compounds. Upon drying,

the peel becomes brittle and suitable for pulverization into a fine powder, which serves as the primary raw material for cosmetic extraction.

2. Phytochemical Profile Relevant to Skin Protection

The cosmetic potential of the drumstick peel arises from its diverse phytochemical composition. Unlike single-compound synthetic actives, plant peels provide a synergistic mixture of bioactive molecules that act simultaneously on multiple pathways of skin damage.

2.1 Polyphenolic Antioxidants

Polyphenols present in the peel function as primary free radical scavengers. Reactive oxygen species generated by UV radiation and pollution attack cellular lipids, proteins, and DNA in skin tissue. Polyphenols neutralize these radicals by donating hydrogen atoms or electrons, thereby stabilizing the reactive species.

Their activity helps prevent

- Lipid peroxidation of skin cell membranes
- Collagen degradation
- Photoaging

2.2 Flavonoids

Flavonoids such as quercetin-like structures are important because they inhibit inflammatory mediators

including prostaglandins and cytokines. Skin inflammation is a central factor in acne, dermatitis, and redness. These molecules also reduce melanocyte stimulation, contributing to mild skin-brightening effects.

2.3 Tannins

Tannins exert an astringent action by precipitating superficial proteins in the stratum corneum. This results in tightening of skin pores and reduction in excessive oil secretion. The pore-tightening effect is particularly valuable in formulations intended for oily or acne-prone skin.

2.4 Saponins

Saponins possess amphiphilic properties and behave as natural surfactants. In cosmetic preparations they:

- Improve foaming ability
- Aid cleansing
- Enhance solubilization of oils

2.5 Carotenoids and Vitamins

Carotenoids function as photoprotective molecules. They absorb portions of ultraviolet radiation and prevent oxidative damage in epidermal cells. Vitamin C supports collagen biosynthesis and improves skin elasticity.

3. Mechanisms of Skin Damage and Role of Peel Phytochemicals

Modern dermatological research identifies four primary pathways responsible for skin aging and damage:

1. Oxidative stress
2. Chronic inflammation
3. Microbial colonization
4. Barrier disruption

Drumstick peel phytochemicals act on each pathway.

Oxidative Stress

UV radiation generates reactive oxygen species within keratinocytes and fibroblasts. These radicals activate matrix metalloproteinases (MMPs), enzymes that degrade collagen. Polyphenols inhibit MMP activation and preserve dermal structure.

Inflammation

Inflammatory mediators such as interleukin-6 and tumor necrosis factor contribute to erythema and acne lesions. Flavonoids suppress these mediators and reduce tissue swelling.

Microbial Activity

Acne-causing bacteria proliferate in sebaceous glands. The peel contains antimicrobial phytoconstituents that disturb bacterial cell membranes, limiting colonization.

Barrier Protection

Environmental pollutants disrupt the lipid barrier of the skin. Tannins and lipid-soluble compounds reinforce surface proteins and improve barrier integrity.

4. Cosmetic Ingredients Derived from Moringa Pod Peel

The peel can be converted into multiple functional cosmetic ingredients rather than a single crude extract.

4.1 Standardized Extract

A hydroalcoholic extract containing quantified phenolic content can be used as an active ingredient in creams and serums.

4.2 Powdered Exfoliant

Finely milled peel powder functions as a gentle exfoliating agent due to its fibrous microstructure.

4.3 Natural Preservative Booster

Polyphenols exhibit antimicrobial effects and can enhance preservation systems in herbal cosmetics.

4.4 Foaming Cleanser Component

Saponin fractions may be incorporated into herbal face wash formulations.

5. Processing and Pre-Treatment of Raw Material

The biological activity of the peel strongly depends on processing conditions.

Cleaning

Peels must be washed to remove soil and microbial contaminants.

Drying

Shade drying at controlled temperature is preferred. Direct sunlight causes degradation of phenolic compounds.

Grinding

Dried peels are milled and sieved to achieve uniform particle size, ensuring consistent extraction efficiency.

Storage

Material should be stored in airtight, light-resistant containers to prevent oxidation and moisture absorption.

6. Extraction Techniques for Cosmetic Use

The extraction method determines the quality and stability of cosmetic actives.

Hydroalcoholic Extraction

A mixture of ethanol and water efficiently extracts both polar and semi-polar compounds.

Aqueous Extraction

Produces mild extracts suitable for sensitive skin but with lower yield.

Ultrasound-Assisted Extraction

Ultrasonic waves disrupt plant cell walls, increasing release of phytochemicals and reducing extraction time.

Microwave-Assisted Extraction

Microwave energy heats intracellular water, causing cell rupture and rapid extraction.

Green extraction techniques are preferred in cosmetic manufacturing because they minimize solvent toxicity and environmental impact.

7. Standardization and Quality Control

For cosmetic application, the extract must be standardized to ensure batch-to-batch uniformity.

Important parameters include:

- Total phenolic content
- Flavonoid concentration
- Microbial limit test
- Absence of heavy metals
- Pesticide residue screening

Chromatographic fingerprinting can be used to confirm authenticity and prevent adulteration.

8. Safety and Dermatological Compatibility

Although plant-based, safety evaluation remains essential. Primary tests include:

- pH compatibility with skin (5.0–6.5)
- Irritation potential
- Allergenicity
- Stability under light and heat

Properly processed moringa peel extract is expected to be non-irritant because it lacks strong essential oils or alkaloids typically responsible for skin reactions.

9. Concept of Nano-Cosmeceuticals

Traditional herbal cosmetics often fail not because the plant is ineffective, but because the active molecules cannot properly reach the target layer of the skin. Human skin is a highly organized barrier system. The outermost layer, the stratum corneum, consists of keratinized cells embedded in a lipid matrix and functions as a biological wall that prevents entry of foreign substances. Most plant extracts remain only on the surface and are easily removed by sweat, sebum, or washing.

Nano-cosmeceuticals aim to overcome this limitation by incorporating active compounds into nanoscale carriers generally ranging from 20–300 nm in diameter. At this scale, particles interact more efficiently with skin lipids, allowing improved penetration and retention. Encapsulation also protects sensitive phytochemicals from oxidation, light degradation, and hydrolysis.

For moringa pod peel extract, nanocarriers are particularly valuable because polyphenols and flavonoids are chemically unstable when exposed to air and UV radiation. Nano-delivery therefore enhances both stability and biological performance

10. Skin Penetration Pathways

Nanocarriers improve dermal delivery through three major pathways.

10.1 Intercellular Route

Particles diffuse between corneocytes through lipid channels. Nanoemulsions and lipid nanoparticles merge with the skin lipid matrix and transport phytochemicals into deeper layers.

10.2 Transcellular Route

Very small particles can pass directly through keratinocytes by partitioning across cellular membranes. Liposomes and flexible vesicles are especially effective through this mechanism.

10.3 Follicular Route

Hair follicles act as reservoirs. Nanoparticles accumulate in follicles and slowly release active compounds over time, providing prolonged therapeutic effect. This route is particularly useful in acne treatment.

11. TYPES OF NANOCARRIERS SUITABLE FOR MORINGA POD PEEL

11.1 Nanoemulsions

Nanoemulsions are dispersions of oil and water stabilized by surfactants with droplet sizes below 200 nm. They are transparent or translucent and have excellent spreadability on skin.

Advantages

- Improved solubility of phytochemicals
- Pleasant skin feel
- Rapid absorption
- Enhanced antioxidant delivery

For moringa peel extract, oil-in-water nanoemulsions are preferred because they are non-greasy and cosmetically elegant. The polyphenols partition into the oil droplets and are gradually released onto the skin surface.

11.2 Liposomes

Liposomes are spherical vesicles composed of phospholipid bilayers resembling cell membranes. Because skin cells also contain phospholipids, liposomes fuse easily with epidermal layers.

Functions in cosmetic delivery

- Transport hydrophilic and lipophilic compounds
- Increase dermal retention
- Reduce irritation potential

Moringa peel flavonoids encapsulated in liposomes can reach the viable epidermis where they exert anti-inflammatory effects.

11.3 Solid Lipid Nanoparticles (SLN)

Solid lipid nanoparticles consist of solid fatty materials stabilized by emulsifiers. At body temperature they remain solid, forming a protective matrix around active molecules.

Key benefits

- Controlled release
- Enhanced photoprotection
- Occlusive effect improving hydration

When applied to skin, SLN form a thin lipid film that reduces transepidermal water loss and enhances moisturization. This is useful for anti-aging formulations.

11.4 Nanostructured Lipid Carriers (NLC)

NLC are second-generation lipid nanoparticles containing a mixture of solid and liquid lipids. They have higher loading capacity than SLN and improved stability. They are particularly suitable for botanical extracts because they can incorporate complex phytochemical mixtures without crystallization.

11.5 Polymeric Nanoparticles

Biodegradable polymers such as chitosan or PLGA can be used to encapsulate moringa peel actives. These systems provide sustained release and targeted follicular deposition.

Chitosan particles additionally possess intrinsic antimicrobial activity, which may synergize with the anti-acne effect of the extract.

12. Preparation Techniques

High-Pressure Homogenization

A coarse emulsion is passed through a narrow gap under high pressure, producing nanosized droplets. Commonly used for nanoemulsions and SLN.

Ultrasonication

Ultrasound waves create cavitation bubbles that break droplets into nanoscale particles. This method is suitable for laboratory-scale preparation.

Solvent Evaporation

Used in polymeric nanoparticles. The polymer and extract are dissolved in an organic solvent, emulsified in water, and solvent is evaporated to form nanoparticles.

Thin-Film Hydration

A phospholipid film is hydrated to produce liposomes. Particle size can be reduced by sonication.

13. Characterization of Nanoformulations

Proper characterization is essential to confirm nanoscale properties.

Particle Size and Distribution

Measured using dynamic light scattering. Smaller particles indicate better penetration potential.

Zeta Potential

Indicates surface charge and predicts physical stability. Values beyond ± 25 mV generally represent stable systems.

Encapsulation Efficiency

Determines how much extract is successfully incorporated within the carrier.

Morphology

Transmission electron microscopy reveals particle shape and structural integrity.

Drug Release Behavior

In vitro diffusion studies evaluate release kinetics. Controlled release indicates prolonged activity.

14. Enhancement of Skin Protection

Nanocarriers enhance skin protection through several mechanisms.

1. Increased antioxidant availability in deeper skin layers
2. Prevention of UV-induced lipid peroxidation
3. Prolonged antimicrobial action in follicles
4. Reinforcement of skin barrier hydration

Additionally, lipid nanoparticles scatter UV light, providing a secondary physical sunscreen effect.

15. Stability Considerations

Plant extracts degrade due to oxidation and photochemical reactions. Encapsulation protects active molecules from environmental exposure. Proper packaging in opaque containers further improves shelf life.

Temperature cycling, centrifugation testing, and long-term storage studies are performed to confirm formulation stability.

16. Integration into Cosmetic Dosage Forms

Nanocarriers can be incorporated into final products such as:

- Serums
- Creams
- Gels
- Lotions
- Sunscreens

Carbopol gels are particularly suitable because they maintain nanoparticle dispersion and provide pleasant skin application.

17. Analytical Region of Analysis (Phytochemical Characterization)

Before cosmetic incorporation, the moringa pod peel extract must undergo detailed analytical characterization to understand which molecules are actually responsible for skin activity. Plant extracts are complex mixtures, and without chemical profiling, reproducibility cannot be achieved.

17.1 Preliminary Phytochemical Screening

Qualitative screening confirms the presence of major metabolite classes such as phenolics, flavonoids, tannins, and saponins. These tests provide only an indication and therefore must be followed by quantitative methods.

17.2 Spectrophotometric Quantification

Total phenolic content is determined using colorimetric reactions where phenolic compounds react with

chromogenic reagents to produce measurable absorbance. Similarly, flavonoids form complexes with metal ions, allowing estimation through UV–visible spectroscopy. These measurements help standardize the extract concentration to ensure consistent biological performance.

17.3 Chromatographic Fingerprinting

High-performance liquid chromatography (HPLC) is particularly important in cosmeceutical research. It separates individual components and produces a characteristic peak pattern. This fingerprint serves as an identity marker and prevents batch variation. Chromatography also detects degradation during storage and processing.

17.4 Stability Analysis

Polyphenols degrade upon exposure to light and oxygen. Accelerated stability testing at elevated temperature and humidity helps predict shelf life. Encapsulation within nanocarriers generally slows degradation and preserves antioxidant capacity.

18. BIOLOGICAL ACTIVITY EVALUATION

18.1 Antioxidant Activity

Antioxidant assays determine the ability of the extract to neutralize free radicals. Free radicals cause oxidative stress in skin cells leading to aging and pigmentation disorders. The extract's radical scavenging ability indicates its protective capacity against environmental stressors such as sunlight and air pollutants.

18.2 Anti-Inflammatory Activity

Inflammation contributes to acne, redness, and irritation. Protein denaturation assays and enzyme inhibition models simulate inflammatory reactions. Reduction in protein denaturation indicates the extract can stabilize cellular proteins and prevent inflammatory responses.

18.3 Antimicrobial Evaluation

Skin hosts multiple microorganisms. Overgrowth of pathogenic bacteria leads to acne and infection. Antimicrobial testing is performed using agar diffusion and minimum inhibitory concentration methods. A significant inhibition zone indicates suitability for anti-acne formulations.

18.4 Tyrosinase Inhibition

Hyperpigmentation results from excessive melanin synthesis. Tyrosinase is the enzyme responsible for melanin production. If the extract inhibits this enzyme, it can function as a mild skin-brightening agent.

19. Evaluation of Nanoformulated Systems

Once incorporated into nanocarriers, additional testing is required.

19.1 In-Vitro Skin Diffusion Study

A synthetic or biological membrane simulates human skin. The nanoformulation is applied to the membrane

and the amount of active compound crossing the barrier is measured over time. Enhanced diffusion compared to crude extract confirms the benefit of nano-delivery.

19.2 Skin Retention Study

After diffusion testing, the membrane is analyzed to measure how much compound remains within the skin layers. High retention is desirable for prolonged cosmetic action.

19.3 Occlusion and Hydration

Lipid nanoparticles form a thin film on the skin surface. Measurement of transepidermal water loss demonstrates whether the formulation improves moisture retention and barrier repair.

20. SAFETY AND DERMATOLOGICAL TESTING

20.1 Irritation Potential

A patch test is conducted on a small skin area. Absence of erythema, itching, or edema suggests dermal compatibility.

20.2 pH Compatibility

Skin maintains a slightly acidic pH. Formulations outside this range may disrupt the microbiome and barrier function. Adjusting formulation pH improves tolerance.

20.3 Phototoxicity

Because cosmetics are exposed to sunlight, phototoxic testing evaluates whether UV exposure causes adverse reactions.

21. Formulation Development and Product Types

Moringa pod peel nano-extract can be used in multiple dermatological and cosmetic products.

Anti-Aging Cream

Nanoparticles deliver antioxidants to dermal fibroblasts, helping maintain collagen structure.

Anti-Acne Gel

Follicular targeting of nanoparticles allows controlled antimicrobial release.

Protective Serum

Lightweight nanoemulsion serums protect against urban pollution and oxidative stress.

Herbal Sunscreen Booster

Polyphenols complement mineral sunscreens by reducing UV-induced oxidative injury.

22. Industrial Processing and Scale-Up

For commercialization, laboratory processes must be scalable. Continuous homogenization systems, controlled temperature reactors, and sterile packaging environments are necessary. Maintaining nanoparticle size distribution during scale-up is critical to preserve efficacy.

Dry extract powder may also be converted into a spray-dried intermediate to improve storage and transportation stability before formulation.

23. Regulatory Considerations

Cosmetic products must meet safety and quality guidelines. Plant-derived ingredients require:

- Absence of heavy metals
- Microbiological safety
- Stability validation
- Non-toxicity certification

Nano-ingredients require additional documentation regarding particle size and dermal safety because regulatory authorities evaluate potential systemic absorption.

24. Novelty and Future Innovation

The uniqueness of moringa pod peel research lies in **waste valorization combined with nanotechnology**. Instead of relying on rare botanical resources, an everyday vegetable by-product becomes a high-value skincare ingredient.

Emerging possibilities include

Smart Responsive Nanogels

Nanogels that release antioxidants when exposed to UV radiation or increased skin temperature.

Microbiome-Friendly Cosmetics

Plant polyphenols may support beneficial skin bacteria while suppressing pathogenic organisms.

Anti-Pollution Dermatological Shields

Nanoparticles forming protective barriers against particulate matter and heavy metals in polluted environments

Combination Phyto-Nanocomplexes

Moringa peel extract can be combined with zinc oxide or hyaluronic acid nanoparticles to create multifunctional formulations providing hydration, protection, and repair simultaneously.

25. Sustainability and Environmental Relevance

Large quantities of vegetable peels are discarded in markets and households. Utilizing this biomass reduces organic waste and environmental burden. Extraction processes using green solvents further improve sustainability.

The approach supports a circular economy where agricultural residues are transformed into commercial products rather than disposed of.

26. Research Translation Potential

Integration of phytochemistry, nanotechnology, dermatology, and cosmetic science creates a multidisciplinary platform. Such research can move from laboratory-scale experimentation to prototype product development and eventually to commercial cosmeceuticals.

Additionally, the low cost of raw material makes it particularly relevant for developing countries where affordable skincare solutions are needed.



FIG. 1: Fresh *Moringa oleifera* (drumstick) pods and peel material used as the raw botanical source for cosmeceutical extraction.



FIG. 2: Preparation of moringa peel extract and formulation process showing homogenization/emulsification to obtain a stable cosmetic base.



FIG. 3: Topical application of moringa-based formulation on facial skin demonstrating its intended dermatological and protective skincare.

LITERATURE REVIEW

Table no. 3 microscopic test.

S. No.	Title of Study	Journal	Author(s)	Methodology	Key Result
1	Antioxidant activity of <i>Moringa oleifera</i> extracts	Journal of Food Science & Nutrition	Sreelatha & Padma (2011)	Ethanol extraction; DPPH and FRAP assays	Strong free-radical scavenging activity indicating anti-aging potential
2	Phytochemical and antimicrobial properties of <i>Moringa oleifera</i>	African Journal of Biotechnology	Bukar et al. (2010)	Aqueous and ethanol extracts tested against bacteria	Significant inhibition of <i>Staphylococcus aureus</i> and <i>E. coli</i>
3	Evaluation of anti-inflammatory effects of <i>Moringa oleifera</i>	Pharmaceutical Biology	Mahajan et al. (2009)	In vitro inflammatory marker suppression	Reduced inflammatory mediators suggesting skin-soothing activity
4	Cosmetic potential of plant polyphenols	Molecules	Nichols & Katiyar (2010)	Review of plant antioxidants in skincare	Polyphenols prevent photoaging and collagen degradation
5	Tyrosinase inhibitory activity of flavonoids	International Journal of Cosmetic Science	Kim et al. (2008)	Enzyme inhibition assay	Flavonoids reduced melanin formation
6	Nanoemulsion based herbal cosmetic delivery	Colloids and Surfaces B	Shakeel et al. (2012)	Nanoemulsion formulation and characterization	Improved skin penetration of plant actives
7	Liposomal delivery systems in cosmetics	International Journal of Pharmaceutics	Verma & Pathak (2010)	Preparation of phospholipid vesicles	Increased dermal absorption and stability
8	Antioxidant and photoprotective effect of botanical extracts	Journal of Dermatological Science	Draeos (2012)	Topical antioxidant evaluation	Reduced UV-induced oxidative damage

9	Solid lipid nanoparticles for topical drug delivery	European Journal of Pharmaceutics	Muller et al. (2002)	SLN preparation and release studies	Controlled release and enhanced skin hydration
10	Herbal anti-acne activity of plant extracts	Journal of Ethnopharmacology	Chomnawang et al. (2005)	Antimicrobial assay on acne bacteria	Effective against <i>Propionibacterium acnes</i>
11	Role of flavonoids in skin protection	Phytotherapy Research	Pietta (2000)	Antioxidant evaluation	Prevented oxidative stress and aging markers
12	Green extraction techniques for plant bioactives	Separation and Purification Technology	Chemat et al. (2017)	Ultrasound & microwave extraction	Higher yield and preserved bioactivity
13	Nanotechnology in cosmeceuticals	Advanced Drug Delivery Reviews	Souto & Müller (2008)	Review of nano-carriers	Improved delivery and prolonged action
14	Antimicrobial and wound healing activity of <i>Moringa</i>	Asian Pacific Journal of Tropical Medicine	Rathi et al. (2006)	In vivo wound healing model	Faster epithelialization and healing
15	Plant-based cosmeceuticals for skin aging	Clinical Dermatology Research	Mukherjee et al. (2011)	Evaluation of botanical skincare agents	Botanical antioxidants improved skin elasticity

CONCLUSION

The evolution of cosmetic science has moved far beyond simple beautification and now intersects strongly with dermatology, material science, and pharmaceutical technology. Modern cosmetic formulations are increasingly designed as functional systems that interact with the biology of the skin rather than merely remaining on its surface. The review highlights that the effectiveness of a cosmetic product is determined not only by the active ingredient but also by the carrier architecture, interfacial chemistry, and controlled delivery behavior within different skin layers. Conventional creams and lotions provided only superficial conditioning, whereas present-day systems—such as nanoemulsions, lipid vesicles, structured gels, and hybrid polymeric matrices—enable improved deposition, targeted delivery, and prolonged residence time of actives.

Ingredient selection has also shifted toward multifunctional materials. Botanical bioactives, peptides, ceramides, antioxidants, and microbiome-supportive agents are now incorporated with carefully optimized excipients to maintain stability and compatibility with the skin barrier. Processing methods including high-pressure homogenization, microfluidization, phase inversion temperature technique, and solvent-free emulsification have contributed to smaller particle size, uniform distribution, and improved sensory attributes. Regional and climatic considerations further influence formulation strategy, as humidity, UV intensity, and environmental pollutants directly affect skin physiology and product performance.

A key emerging concept is the integration of therapeutic intent within cosmetic boundaries. Products are now designed to support barrier repair, oxidative stress reduction, hydration regulation, and controlled release of protective molecules without crossing into pharmaceutical classification. The review therefore

emphasizes a transition from decorative cosmetics to bio-responsive and performance-driven dermal systems. Future cosmetic research will likely focus on personalization, skin microbiome compatibility, sustainable materials, and intelligent carriers capable of responding to pH, temperature, or sebum variations. Thus, cosmetic formulations are becoming scientifically engineered skin-interaction platforms rather than simple topical preparations.

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