Current Pharmaceutical Research (CPR)
Vol 1, Issue 3, July-September 2025
Journal Homepage: https://cpr.org.in/

Rutin Nanoparticles: Pioneering New Frontier skincare

[1]Deep Sharma[*], [2]Kamal Jeet, [1]Anjana Devi, [1]Vijay Sharma, [1]Vivek Sharma

[1]Research scholar, Department of Pharmacy, School of Pharmaceutical and Health Sciences, Carrier Point University, Hamirpur-177001, India
[2]Principal, SFC Institute of Pharmacy, Moga, Punjab, India

Keywords

Rutin-loaded nanoparticles, Dermatological applications, Nanotechnology, Skin health, Topical drug delivery, Bioavailability enhancement.

Abstract

Dermatological issues, spanning from common inflammatory conditions to skin aging and cancers, present significant challenges for effective treatment. The application of topical medications provides a promising method to specifically target skin problems while reducing systemic side effects. Rutin, a naturally occurring flavonoid recognized for its strong antioxidant, anti-inflammatory, and healing properties, presents considerable therapeutic potential for various dermatological applications. However, its limited ability to penetrate the skin and low bioavailability hinder its clinical effectiveness. Nanotechnology provides a practical solution to overcome these challenges by encapsulating Rutin in nanoparticles. This review examines the potential of Rutin-loaded nanoparticles as innovative surface modification techniques for skin-related uses. We explore the benefits of Rutin for skin health, the advantages of nanoparticle-delivery systems that are based on collaboration, alongside the joint effects of integration Rutin employing nanotechnology to improve local effectiveness. In addition, we investigate the different types of nanoparticles suitable for Rutin encapsulation, their techniques for enhancing drug delivery, and the promising preclinical and recent clinical information supporting the use of Rutin-loaded nanoparticles in tackling skin ailments. In the end, we explore the challenges and potential avenues for transforming this innovative approach into effective clinical topical therapies.

***Corresponding Author:**
Mr. Deep Sharma (deeppharma86@gmail.com)

Article Info
Received: 15 July 2025, Received in revised form: 12 December 2025, Accepted: 12 December 2025, Available online: 13 December 2025

DOI: https://doi.org/10.63785/cpr.2025.1.3. 348363

1. Introduction

The skin, acknowledged as the largest organ in the human body, plays an essential role as a protective barrier against outside factors. It is vulnerable to various skin-related issues, including inflammatory conditions like eczema and psoriasis, infectious diseases, and skin cancers, pigmentary disorders, and the effects of aging [1]. Topical therapies are crucial in skin care, providing a focused approach to apply medical agents directly to the affected areas, which reduces overall exposure and potential side effects. However, the outer layer corneum, the epidermis, poses a significant barrier for drug absorption, diminishing the effectiveness of multiple topical therapies [2].

Rutin (quercetin-3-O-Rutinoside), a common flavonoid found in plants such as buckwheat, citrus fruits, and apples, has garnered significant interest due to its various biological impacts, including strong antioxidant and anti-inflammatory characteristics, vasoprotective, and influences on wound recovery [3]. These therapeutic properties position Rutin as a practical option for addressing different skin issues, such as indications of aging, hyperpigmentation, inflammatory skin disorders, and tissue restoration. However, Rutin's natural physicochemical characteristics, including low water solubility and decreased permeability through the stratum corneum, and rapid metabolism, pose challenges for its effective topical use and absorption at the desired site within the skin [4].

Nanotechnology, which enables the alteration of substances at the nanoscale (1-100 nm), provides innovative solutions to address the limitations of traditional topical drug delivery. Various types of nanoparticles, such as liposomes, solid lipid nanoparticles (SLNs), nanostructured lipid

transporters (NLCs), polymer-based nanoparticles, and metallic nanoparticles, can encapsulate therapeutic agents like Rutin [5]. This encapsulation enhances skin penetration, supports controlled release, and allows for targeted delivery. By incorporating Rutin into nanoparticles, we can boost its solubility, protect it from degradation, enhance its ability to infiltrate the layer corneum, and promote its accumulation at the specific region within the skin. This analysis seeks to investigate the joint efficacy of Rutin-loaded nanoparticles as creative regional treatment methods for various skin-related applications, emphasizing the benefits, challenges, and potential advancements in this rapidly evolving field [6].

2. Rutin as Bioactive Compound

Rutin, a glycosylated derivative of quercetin and part of the flavonoid class of polyphenolic compounds, have diverse pharmacological impacts that are significant for skin wellness [7].

2.1 Antioxidant Properties

Oxidative stress, caused by reactive oxygen species (ROS) due to exposure to UV rays, environmental pollution, and routine metabolic processes, is a key factor in the development of numerous skin problems, including aging, inflammation, and skin cancer [8]. Rutin exhibits strong antioxidant properties by counteracting free radicals, hindering lipid peroxidation, and improving the activity of natural antioxidant enzymes such as superoxide dismutase (SOD) and catalase. This antioxidant capability of Rutin can shield skin cells from oxidative harm, reducing the negative impacts of environmental stressors and promoting skin health and anti-aging [9].

2.2 Anti-inflammatory Activity

Inflammation plays a vital role in many skin conditions, such as eczema, psoriasis, and acne. Rutin has shown considerable anti-inflammatory properties by influencing multiple inflammatory pathways. It can reduce the production of pro-inflammatory cytokines like TNF-α, IL-1β, andIL-6, and impede the activity of inflammatory enzymes such as cyclooxygenase-2 (COX-2) and inducible nitric oxidesynthase (iNOS). By reducing the concentrations of inflammatory substances, Rutin may help reduce skin irritation, redness, and itching, making it a potential treatment for inflammatory skin issues [10].

2.3 Wound Healing Promotion

Wound healing is a multifaceted process that encompasses cell growth, movement, and the restructuring of the extracellular matrix. Rutin has been demonstrated to enhance the healing process of wounds by promoting collagen production, the creation of new blood vessels, and the renewal of the skin layer [11]. It can support the growth and movement of fibroblasts, boost collagen accumulation, and foster the maturation of blood vessels at the injury location, ultimately leading to quicker and more effective wound closure. These attributes make Rutina promising option for external use in managing wounds and promoting healing from burns [12].

2.4 Skin Pigmentation Modulation

Hyperpigmentation issues, such as melasma and post-inflammatory hyperpigmentation, are common issues related to the skin. Rutin has demonstrated potential in controlling skin color by inhibiting melanogenesis, the process responsible for melanin production [13]. It can decrease the activity of tyrosinase, an essential enzyme in melanin production, and interfere with the transfer of melanosomes to keratinocytes. This ability to inhibit melanogenesis indicates that Rutin might be advantageous in tackling hyperpigmentation issues and promoting a more uniform skin tone [14].

2.5 Photoprotective Effects

Ultraviolet (UV) radiation significantly contributes to the aging process of the skin, hyperpigmentation, and the development of skin cancer. Rutin has shown photoprotective properties by absorbing UV radiation, counteracting reactive oxygen species (ROS) generated by UV exposure, and safeguarding DNA from photo damage. Applying Rutin applying it to the skin could help reduce damage caused by UV rays, which encompasses erythema, photoaging, and the probability of skin cancers [15].

3. Nanoparticles as Distribution Mechanisms for Enhanced Surface Delivery

Nanotechnology provides a flexible approach to enhance the surface utilization of bioactive compounds such as Rutin. Due to their unique physicochemical characteristics such as tiny size, large surface area, and customizable surface features nanoparticles can address the limitations of traditional topical preparations and improve the delivery of drugs to the skin [16].

Figure 1 illustrates the conceptual mechanism by which rutin-loaded nanoparticles enhance the delivery and therapeutic action of rutin within skin layers. The diagram shows that the nanoparticles, encapsulating rutin molecules, interact with the outermost layer of the skin the stratum corneum and penetrate through it via both intercellular and transcellular pathways[17]. Upon penetration, these nanoparticles gradually release rutin into the epidermis and dermis, ensuring a sustained and controlled release of the bioactive compound. This facilitates deeper skin absorption, increased local concentration, and prolonged therapeutic effects. The encapsulation protects rutin from degradation due to light, oxidation, or enzymatic activity, thereby improving its stability, bioavailability, and efficacy [18].

The figure visually represents how nanoparticle-based delivery systems overcome the skin's natural barrier and enhance rutin's antioxidant, anti-inflammatory, and wound-healing actions, making them a promising strategy for advanced dermatological therapy.

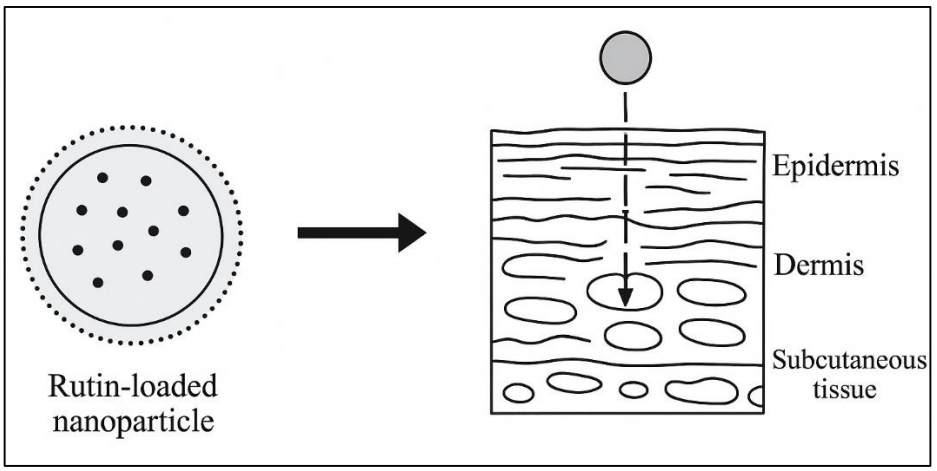

Figure 1: Schematic Representation of Rutin-Loaded Nanoparticles and Their Mechanism for Enhanced Skin Penetration.

3.1 Enhanced Skin Penetration

The tiny size of nanoparticles allows them to penetrate the layer corneum effectively, either through the intercellular route (between corneocytes) or the transcellular route (through corneocytes). Nanoparticles can navigate through the tight passages of the layer corneum, delivering Rutin deeper into the epidermis and dermis, thereby reaching target cells and tissues more efficiently than larger drug carriers or free drug molecules [19].

3.2 Controlled and Sustained Release

Delivery systems based on nanoparticles can be configured to provide controlled and extended distribution of Rutin directly at the target site. This method of administration can improve the therapeutic effects, decrease the frequency of doses, and lessen the potential side effects that arise from varying drug concentrations in the skin. Various nanoparticle materials and production methods can be utilized to customize the release kinetics of Rutin, ensuring that the efficacy of the therapy is maintained throughout time [20].

3.3 Targeted Distribution and Enhanced Bioavailability

Nanoparticles can be adjusted with targeting ligands, such as antibodies, peptides, or aptamers, to particularly target unhealthy skin cells or tissues. This exact technique can improve the local concentration of Rutinat the action location, enhancing its therapeutic effectiveness while minimizing off-target impacts. Additionally, enclosing Rutin in nanoparticles can shield it from degradation caused by enzymes and metabolic activities in the skin, thereby improving its bioavailability and extending its therapeutic impacts [21].

3.4 Improved Formulation Durability and Cosmetical Acceptability

Nanoparticles can enhance the physicochemical stability of Rutin, safeguarding it from degradation due to light, oxidation, or hydrolysis. This improved stability can prolong the shelf life of topical products. Furthermore, nanoparticle-based creations can be transformed into aesthetically pleasing objects that offer enhanced texture, spreadability, and tactile feeling, which could lead to better patient compliance and approval [22].

4. Rutin-Loaded Nanoparticles: Joint Opportunities for Skin Therapies

The combination of Rutin's therapeutic properties coupled with the benefits of nanoparticle-based drug delivery promotes a cooperative strategy for developing innovative topical treatments for an array of skin conditions [23].

4.1 Rutin-Loaded Nanoparticles for Inflammatory Skin Disorders

Rutin-loaded nanoparticles have shown considerable promise in treating inflammatory skin conditions like eczema, psoriasis, and dermatitis. By encapsulating Rutin in nanoparticles, its ability to penetrate the skin is enhanced, allowing targeted delivery to inflamed areas within the epidermis and dermis [24]. The extended release from these nanoparticles can extend the anti-inflammatory advantages of Rutin, helping to alleviate skin redness, itching, and overall inflammation. Research conducted on animal models of dermatitis and psoriasis has demonstrated that the topical application of Rutin-loaded nanoparticles significantly lowers skin irritation, enhances epidermal thickness, and the amounts of inflammatory markers compared to free Rutin or traditional formulations [25].

4.2 Rutin-Loaded Nanoparticles for Age-Defiance and Dermal Shielding

The antioxidant and photoprotective qualities of Rutin, combined with enhanced skin absorption via nanoparticles, position Rutin-loaded nanoparticles as an effective approach for safeguarding skin and combating aging. These nanoparticles can efficiently transport Rutin into the more profound layers of the skin, safeguarding skin cells from oxidative harm initiated by UV rays, degradation of collagen, and signs of photoaging [26]. Rutin's ability to stimulate collagen production and its antioxidant properties can aid in minimizing wrinkles, enhancing skin elasticity, and contributing to a more youthful appearance. Items containing Rutin-loaded nanoparticles can be blended with sunscreens and anti-aging products to boost their effectiveness and offer prolonged protection against environmental influences [27].

4.3 Rutin-Loaded Nanoparticles for Wound

Healing

The wound-healing effects of Rutin can be greatly enhanced through the utilization of nanoparticle delivery systems. These Rutin-loaded nanoparticles boost the efficiency of medication uptake at the injury location, allowing for an ongoing release of Rutin that encourages fibroblast growth, collagen production, and the formation of new blood vessels [28]. Research indicates that employing Rutin-loaded nanoparticles. Administering therapies directly to wound models leads to faster wound recovery, improved collagen formation, and enhanced re-epithelialization in relation to treatments employing free Rutin. This points to the capacity of Rutin-loaded nanoparticles as an effective method for speeding up the healing process in chronic injuries, burns, and surgical cuts [29].

4.4 Rutin-Loaded Nanoparticles for Hyperpigmentation Disorders

Rutin's ability to inhibit melanogenesis, combined with nanoparticle delivery, provides a focused strategy for addressing hyperpigmentation disorders. These nanoparticles can transport Rutin directly to the melanocytes in the outer skin layer, effectively preventing tyrosinase activity and diminished melanin production [30]. The controlled release from the nanoparticles allows an extended inhibition of melanogenesis, resulting in a progressive and effective enhancement of skin luminosity. Additional research is required to assess the effectiveness of Rutin-loaded nanoparticles in treating specific hyperpigmentation issues such as melasma and post-inflammatory hyperpigmentation in clinical environments [31].

5. Types of Nanoparticles for Rutin Delivery and Formulation Strategies

The types of nanoparticles used for Rutin delivery include liposomes, solid lipid nanoparticles (SLNs), nanostructured lipid carriers (NLCs), polymeric nanoparticles, metallic nanoparticles, and nanoemulsions. Liposomes enhance skin hydration but may face stability issues, while SLNs and NLCs offer better stability, drug loading, and controlled release [32]. Polymeric nanoparticles, such as those made from biodegradable polymers like chitosan and PLGA, provide customizable drug release and targeting. Metallic nanoparticles, like gold and silver, offer antimicrobial properties but require careful evaluation for toxicity, and nanoemulsions improve solubility and penetration for poorly water-soluble drugs like Rutin. Each nanoparticle type has unique advantages and is chosen based on the intended therapeutic application, stability, and biocompatibility [33].

Table 1 provides an extensive overview of various nanoparticle types used for encapsulating Rutin, a bioactive compound with significant therapeutic potential for skin-related conditions. The table summarizes the key characteristics, advantages, and limitations of 40 different nanoparticle types, including liposomes, solid lipid nanoparticles (SLNs), polymeric nanoparticles, and metallic nanoparticles, among others [34]. Each type of nanoparticle is assessed based on its ability to encapsulate and deliver Rutin effectively to the skin, enhancing its bioavailability, stability, and therapeutic effects. For example, liposomes are known for their ability to improve skin hydration and absorption but face challenges with stability. In contrast, solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs) provide enhanced stability and controlled release, making them ideal for sustained drug delivery. Polymeric nanoparticles, made from biodegradable materials like PLGA and chitosan, offer customizable drug release profiles and targeted delivery capabilities [35].

The table also addresses the limitations of certain nanoparticles, such as potential toxicity concerns with metallic nanoparticles (e.g., gold and silver), or the difficulty of scaling production for some nanoparticle types. Additionally, it highlights the advantages of specific nanoparticles in improving skin penetration, increasing the solubility of poorly water-soluble drugs like Rutin, and offering targeted therapy for skin conditions such as inflammation, hyperpigmentation, and aging. This table serves as a comprehensive reference for researchers and formulators in the field of nanomedicine, helping to guide the selection of appropriate nanoparticles for Rutin encapsulation based on their unique characteristics and intended therapeutic applications [36].

Table 1: Overview of Nanoparticle Types for Rutin Encapsulation and Their Characteristics.

S. No.	Nanoparticle Type	Characteristics	Advantages	Limitations	Applications	References
1.	Liposomes	Bilayer membrane, phospholipids, encapsulate hydrophilic and hydrophobic drugs.	Improve skin hydration, enhance absorption.	Stability issues, leakage.	Topical drug delivery, skin hydration.	[37]
2.	Solid Lipid Nanoparticles (SLNs)	Solid lipids at room temperature, biodegradable.	High drug loading, controlled release, enhanced stability.	Low solubility of some drugs, limited drug encapsulation.	Anti-aging, wound healing.	[38], [39]
3.	Nanostructured Lipid Carriers (NLCs)	Combination of solid and liquid lipids, stable.	Increased drug loading capacity, controlled release, biocompatibility.	Expensive to produce, limited shelf life.	Skin penetration, wound healing.	[40]
4.	Polymeric Nanoparticles	Biodegradable polymers like PLGA, chitosan, and hyaluronic acid.	Customizable release profiles, targeted drug delivery, biocompatibility.	Complex preparation, potential for polymer degradation.	Anti-inflammatory, skin pigmentation.	[41]
5.	Metallic Nanoparticles	Gold, silver, and other metals.	Antimicrobial, diagnostic applications, enhanced stability.	Potential toxicity, need for careful evaluation.	Antimicrobial, cancer diagnostics.	[42], [43]
6.	Nanoemulsions	Stable mixtures of oil and water, small droplet size.	Solubilize poorly water-soluble drugs, enhance skin penetration.	Stability issues under storage conditions.	Skin penetration, targeted delivery.	[44]
7.	Microemulsions	Thermodynamically stable, oil-water mixtures.	Enhanced solubility and bioavailability.	Limited to specific drugs, expensive.	Skin penetration, anti-aging.	[45]
8.	Dendrimers	Branched, tree-like structures, precise drug loading.	High drug-loading capacity, targeted drug delivery.	Expensive synthesis, potential for toxicity.	Cancer therapy, targeted delivery.	[46], [47]
9.	Polymeric Micelles	Amphiphilic block copolymers forming micelles.	Improved solubility, prolonged release, targeted delivery.	Limited drug loading, instability in aqueous media.	Drug delivery, anti-aging.	[48]
10.	Gold Nanoparticles	Spherical, biocompatible gold structures.	Stability, non-toxic, excellent for surface functionalization.	Potential cytotoxicity, difficult synthesis.	Diagnostics, anti-inflammatory.	[49]
11.	Silver Nanoparticles	Small, spherical silver particles, antimicrobial.	Antimicrobial properties, long shelf life.	Risk of cytotoxicity, stability issues.	Wound healing, antimicrobial skin care.	[50]
12.	Chitosan Nanoparticles	Derived from chitin, biodegradable.	Biocompatible, enhanced drug stability, mucoadhesive properties.	Limited drug load, susceptibility to moisture.	Wound healing, tissue engineering.	[51]
13.	Poly(lactic-co-glycolic acid) Nanoparticles (PLGA)	Biodegradable copolymer, controlled release.	Safe, FDA-approved, customizable release kinetics.	Expensive to manufacture, slow degradation.	Cancer therapy, wound healing.	[52]

14.	Niosomes	Non-ionic surfactants forming bilayer vesicles.	Non-toxic, cost-effective, improved skin penetration.	Less stability than liposomes, limited shelf life.	Topical drug delivery, skin protection.	[53]
15.	Magnetite Nanoparticles	Iron oxide nanoparticles with magnetic properties.	Targeted drug delivery using magnetic fields, biocompatible.	Toxicity concerns, limited targeting efficiency.	Cancer therapy, drug targeting.	[54]
16.	Carbon Nanotubes	Hollow, cylindrical nanostructures of carbon.	High surface area, excellent mechanical properties, enhanced skin penetration.	Toxicity concerns, difficult synthesis.	Drug delivery, skin care.	[55]
17.	Nano-structured Silica	Mesoporous silica with high surface area.	Excellent for controlled release, biocompatible.	Risk of aggregation, difficult to functionalize.	Controlled release, drug delivery.	[56]
18.	Cyclodextrin Nanoparticles	Cyclodextrin-based particles.	Improve solubility of hydrophobic drugs, biocompatible.	High cost, slow production.	Drug solubilization, skin hydration.	[57]
19.	Poly(lactic acid) Nanoparticles (PLA)	Biodegradable, sustainable polymer nanoparticles.	Biocompatible, biodegradable, slow degradation rates.	Limited drug load, risk of polymer degradation.	Controlled release, anti-aging.	[58]
20.	Lipid-Core Micelles	Lipid core surrounded by surfactants.	Enhanced solubility, stability in skin applications.	Risk of aggregation, instability in certain media.	Drug delivery, anti-aging.	[59]
21.	Calcium Phosphate Nanoparticles	Biocompatible and biodegradable calcium-based nanoparticles.	High loading capacity, controlled release, cost-effective.	Difficult synthesis, potential for toxicity.	Bone regeneration, tissue engineering.	[60]
22.	Polyethylenimine Nanoparticles	Cationic polymer-based particles.	Efficient gene delivery, improved bioavailability.	Toxicity in high concentrations.	Gene delivery, anticancer therapy.	[61]
23.	Polyvinyl Alcohol Nanoparticles	Hydrophilic, biodegradable polymer nanoparticles.	High drug loading, enhanced skin penetration, biocompatible.	Limited stability, difficult to scale up production.	Topical therapies, wound healing.	[62]
24.	Nanocrystals	Crystalline nanoparticles of active ingredients.	Increased surface area, enhanced solubility.	Risk of aggregation, limited to specific drugs.	Drug delivery, solubility enhancement.	[63]
25.	Eudragit Nanoparticles	Biodegradable copolymers of methacrylic acid and methacrylate.	High drug loading capacity, biocompatible, stable.	Limited drug release, expensive.	Controlled release, anti-aging.	[64]
26.	Zinc Oxide Nanoparticles	Biocompatible nanoparticles of zinc oxide.	UV protection, antimicrobial properties.	Risk of skin irritation, need for careful evaluation.	Sun protection, anti-aging.	[65]

27.	Polyethylene Glycol (PEG) Nanoparticles	Hydrophilic, biocompatible nanoparticles.	Improved solubility, stability, and bioavailability.	Risk of immunogenicity, possible toxicity at high doses.	Drug delivery, skin hydration.	[66]
28.	Polypropylenglycol Nanoparticles	Biodegradable and hydrophilic nanoparticles.	Good skin penetration, biocompatible, controlled release.	Limited stability, risk of irritation.	Drug delivery, wound healing.	[67]
29.	Polyvinylpyrrolidone (PVP) Nanoparticles	Hydrophilic, water-soluble synthetic polymer.	High solubility, controlled drug release.	Limited stability, potential toxicity.	Drug delivery, wound healing.	[68]
30.	Dendritic Polymers	Highly branched polymer structures with functional groups.	High surface area, precise drug loading, targeted drug delivery.	Expensive, potential toxicity.	Drug delivery, cancer therapy.	[69]
31.	Polysaccharide Nanoparticles	Derived from natural polysaccharides like alginate, chitosan.	Biocompatible, biodegradable, excellent skin penetration.	Limited drug loading capacity, instability.	Drug delivery, wound healing.	[70]
32.	Cationic Lipid Nanoparticles	Lipid-based nanoparticles with positive charge.	High efficiency in gene delivery, skin penetration.	Cytotoxicity at high concentrations, stability issues.	Gene therapy, skin penetration.	[71]
33.	Polyethyleneimine (PEI) Nanoparticles	Polymeric nanoparticles for efficient drug encapsulation.	High encapsulation efficiency, targeted delivery.	Cytotoxicity, stability issues in certain formulations.	Cancer therapy, gene delivery.	[72]
34.	Co-polymers	Blended polymers offering dual functionality.	Customizable for specific delivery applications, biocompatible.	Complex synthesis, potential for toxicity.	Drug delivery, targeted therapy.	[73]
35.	Polycarboxylate Nanoparticles	Biodegradable and biocompatible copolymers.	High drug encapsulation, controlled release, cost-effective.	Risk of polymer degradation, limited drug types.	Skin hydration, drug delivery.	[74]
36.	Silicon Nanoparticles	High surface area, biocompatible nanostructures.	High drug-loading, stable formulations.	Aggregation in solution, difficult scaling.	Drug delivery, skin protection.	[75]
37.	Hydrogel Nanoparticles	Nanoparticles encapsulated in hydrogels for sustained release.	Excellent for wound healing, controlled release of active ingredients.	Limited drug types, potential irritation.	Wound healing, skin regeneration.	[76]
38.	Supramolecular Nanoparticles	Non-covalent assemblies of molecules in a self-assembled manner.	High drug encapsulation, targeted delivery, enhanced stability.	Synthesis complexity, instability under certain conditions.	Drug delivery, anti-aging.	[77]
39.	Quantum Dots	Semiconductor nanocrystals with optical properties.	High surface area, excellent for diagnostic and imaging applications.	Potential toxicity, difficult synthesis.	Diagnostics, drug delivery.	[78]
40.	Nanogels	Nanoparticles with cross-linked polymer networks.	High drug loading, controlled release, responsive to environmental stimuli.	Potential instability, synthesis challenges.	Drug delivery, tissue engineering.	[79]

5.1 Liposomes
These are structures encased in membranes made up of lipids bilayers, acknowledged for their synergy with biological frameworks and their capacity for natural decomposition. They can encapsulate both hydrophilic and hydrophobic pharmaceuticals, encompassing Rutin. While liposomes can improve skin hydration and absorption, their stability could pose challenges [80].

5.2 Solid Lipid Nanoparticles (SLNs) and Nanostructured Lipid Carriers (NLCs)
Composed of solid lipids (SLNs) or a combination of solid and liquid lipids (NLCs), these nanoparticles provide enhanced stability, increased drug loading capacity, and controlled release when compared to liposomes. They are similarly very compatible with biological systems and cost-effective for large-scale manufacturing [81].

5.3 Polymeric Nanoparticles
Biodegradable and biocompatible polymers like chitosan, PLGA, and hyaluronic acid can be utilized to create polymeric nanoparticles for Rutin encapsulation. These nanoparticles can be customized for specific drug release profiles, surface modifications for targeting, and improved stability [82].

5.4 Metallic Nanoparticles
Gold and silver nanoparticles, primarily studied for their antimicrobial properties or employed as diagnostic tools, can also serve as carriers for Rutin. However, potential toxicity and compatibility issues must be carefully evaluated when employing metallic nanoparticles [83].

5.5 Nanoemulsions and Microemulsions
These are uniform blends of oil and water that remain stable either thermodynamically or kinetically, and are maintained by surfactants. They can solubilize poorly water-soluble drugs like Rutin and improve skin penetration. Choosing the right type of nanoparticle and the formulation strategy depends on various factors, including the desired drug release pattern, targeted area within the skin, stability needs, biocompatibility, and manufacturing feasibility. Optimizing the nanoparticle formulation comprises elements like particle dimensions and surface characteristics is crucial for achieving maximum treatment efficacy and skin suitability [84].

6. Advantages, Challenges, and Future Directions
6.1 Advantages of Rutin-Loaded Nanoparticles
Nanoparticles offer a significant advancement in the topical delivery of Rutin, enhancing its absorption through the skin and ensuring that it reaches the intended site effectively. This technology allows for controlled and sustained release, providing extended therapeutic benefits and reducing the need for frequent dosing [85]. Furthermore, nanoparticles can be customized for targeted delivery, directing the active compound precisely to specific skin cells or tissues, improving treatment efficacy. In addition to their therapeutic advantages, nanoparticles contribute to the overall stability and uniformity of topical formulations, improving their aesthetic appeal and making them more cosmetically acceptable. By focusing on localized treatment, this approach also minimizes the risk of systemic side effects, which is a common concern with oral or injectable delivery methods [86].

6.2 Challenges and Future Directions
The development of nanoparticles for Rutin delivery faces several challenges that need to be addressed for their widespread application. One major issue is scalability and production costs, as manufacturing nanoparticles on a large scale at an affordable price remains a significant hurdle to ensuring economic viability [87]. Additionally, long-term consistency and duration are crucial to ensure that nanoparticle-based formulations maintain their stability and effectiveness throughout their shelf life, making them marketable and reliable for consumers. Skin irritation and safety concerns also require thorough evaluation, as potential toxicity and the long-term safety of nanoparticles must be carefully considered before they can be widely adopted in dermatological products [88].

The transition from preclinical studies to clinical trials and eventually to market-ready products presents another obstacle. This process demands comprehensive clinical evaluations and regulatory approvals to ensure that the formulations are both effective and safe for widespread use. Furthermore, personalized dermatology holds promise for the future, with research focused on tailoring Rutin-loaded nanoparticle formulations to meet individual patient needs and target specific skin concerns. Combining these nanoparticles with other active ingredients or treatment strategies could enhance therapeutic efficacy, presenting an exciting area for further exploration [89].

To overcome these challenges, future research should focus on advanced nanomaterial design, improved formulation methods, and thorough biocompatibility and safety assessments. Additionally, investigating innovative nanomaterials and surface modification techniques will be key to advancing the field and improving the overall performance of Rutin-loaded nanoparticle therapies [90].

Conclusion
Rutin-loaded nanoparticles offer a creative method to improve the localized management and therapeutic effectiveness of Rutin in skincare. By addressing the constraints of traditional topical products, these nanoparticles can efficiently transport Rutin to specific areas of the skin, enhancing its antioxidant, anti-inhibitory, tissue-healing, and pigment-modulating characteristics. Initial studies have shown considerable potential of Rutin-loaded nanoparticles in tackling various skin issues, such as inflammatory conditions, signs of aging, wounds, and hyperpigmentation. Despite current challenges pertaining to scalability, stability, and real-world implementation in medical environments, ongoing research and technological improvements are facilitating the creation of effective and clinically applicable topical treatments using Rutin-loaded nanoparticles. This innovative approach has the potential to transform dermatological care and improve outcomes for those dealing with various skin conditions.

Acknowledgement
We sincerely thank the Department of Pharmacy, School of Pharmaceutical and Health Sciences, Career Point University, Hamirpur, for providing the necessary resources and support. Our deepest gratitude goes to the Principal of SFC Institute of Pharmacy, Moga, Punjab, for their guidance. We also appreciate the invaluable contributions of our colleagues and families for their continuous encouragement throughout this research.

Author Contribution
DS; Conceptualized the study, KJ; Visualization, and AD; Prepared the manuscript draft, VS; Data Collection, VS; Proofreading.

Conflict of Interest
No conflicts of interest are disclosed by the authors.

Source of Funding
There is no funding available to conduct this study.

Reference

1. R. Saha, S. Patkar, M. M. Pillai, and P. Tayalia, "Bilayered skin substitute incorporating rutin nanoparticles for antioxidant, anti-inflammatory, and anti-fibrotic effect," Biomater. Adv., 2023, doi: 10.1016/j.bioadv.2023.213432.
2. S. Saha and A. Mishra, "A facile preparation of rutin nanoparticles and its effects on controlled growth and morphology of calcium oxalate crystals," J. Cryst. Growth, 2020, doi: 10.1016/j.jcrysgro.2020.125635.
3. H. Wu et al., "Rutin-Loaded Silver Nanoparticles With Antithrombotic Function," Front. Bioeng. Biotechnol., 2020, doi: 10.3389/fbioe.2020.598977.
4. S. Luo, Y. Fu, J. Ye, and C. Liu, "Encapsulation of rutin in protein nanoparticles by pH-driven method: impact of rutin solubility and mechanisms," J. Sci. Food Agric., 2024, doi: 10.1002/jsfa.13068.
5. H. T. H. Vu, S. Streck, S. M. Hook, and A. McDowell, "Utilization of Microfluidics for the Preparation of Polymeric Nanoparticles for the Antioxidant Rutin: A Comparison with Bulk Production," Pharm. Nanotechnol., 2019, doi: 10.2174/2211738507666191019141049.
6. R. C. Pedrozo, E. Antônio, N. M. Khalil, and R. M. Mainardes, "Bovine serum albumin–based nanoparticles containing the flavonoid rutin produced by nano spray drying," Brazilian J. Pharm. Sci., 2020, doi: 10.1590/s2175-97902019000317692.
7. K. Kizilbey, "Optimization of Rutin-Loaded PLGA Nanoparticles Synthesized by Single-Emulsion Solvent Evaporation Method," ACS Omega, 2019, doi: 10.1021/acsomega.8b02767.
8. M. R. Khan, D. Kumar, S. Shamim, K. Sunand, S. Sharma, and G. Rawat, "Ethnopharmacological relevance of Citrus limon (L.) Burm. f. as adjuvant therapy," Ann. Phytomedicine An Int. J., vol. 12, no. 2, pp. 169–179, 2023, doi: 10.54085/ap.2023.12.2.19.
9. M. J. dos Santos Alves et al., "Starch nanoparticles containing phenolic compounds from green propolis: Characterization and evaluation of antioxidant, antimicrobial and digestibility properties," Int. J. Biol. Macromol., 2024, doi: 10.1016/j.ijbiomac.2023.128079.
10. E. Tobar-Delgado, D. Mejía-España, O. Osorio-Mora, and L. Serna-Cock, "Rutin: Family Farming Products' Extraction Sources, Industrial Applications and Current Trends in Biological Activity Protection," 2023. doi: 10.3390/molecules28155864.
11. S. Ilbasmis-Tamer, E. S. Saral-Acarca, S. Tort, Ç. Yücel, U. Tamer, and F. Acartürk, "Fabrication and characterization of starch-copper nanoparticles/rutin nanofiber hybrid scaffold," J. Drug Deliv. Sci. Technol., 2022, doi: 10.1016/j.jddst.2022.103401.
12. M. G. Raju, M. Srivani, N. V. L. Suvarchala Reddy, and G. S. Priya, "Formulation and Characterization of Rutin Loaded Chitosan Nanoparticles," Asian J. Res. Med. Pharm. Sci., 2022, doi: 10.9734/ajrimps/2022/v11i130180.
13. S. A. Ali, S. Ali, S. Rastogi, B. Shivhare, and M. Muztaba, "A Comprehensive Review on Advancements in Nanocarriers-Based Peptide Delivery for Cancer Therapeutics," Micro Nanosyst., vol. 17, no. 4, pp. 283–297, 2025, doi: 10.2174/0118764029358553250325040749.
14. G. Kamaris, A. Dalavitsou, and C. K. Markopoulou, "Development and Validation of an HPLC-DAD Method for the Determination of Seven Antioxidants in a Nano-Emulsion: Formulation and Stability Study," Separations, 2024, doi: 10.3390/separations11020043.
15. A. Hedayati, F. Naseri, E. Nourozi, B. Hosseini, H. Honari, and S. Hemmaty, "Response of Saponaria officinalis L. hairy roots to the application of TiO2 nanoparticles in terms of production of valuable polyphenolic compounds and SO6 protein," Plant Physiol. Biochem., 2022, doi: 10.1016/j.plaphy.2022.03.001.
16. Sutrino, "Pengaruh Pelatihan Kerja, Kompetensi Sdm Dan Motivasi Kerja Terhadap Kinerja Karyawan Pada Ud Afalia Jaya Tumpang Malang," Molecules, 2019.
17. M. Mendoza and O. Rodríguez, "COMPARACIÓN DE PARÁMETROS FÍSICO-QUÍMICOS DE COMPRIMIDOS DE CARVEDILOL DE 25MG GENÉRICO FRENTE AL MEDICAMENTO INNOVADOR," Molecules, 2022.
18. A. Kinicki and M. Fugate, "Organizational behavior," McGraw Hill Educ., 2020.
19. W. Eaknai et al., "Ethanolic Fenugreek Extract: Its Molecular Mechanisms against Skin Aging and the Enhanced Functions by Nanoencapsulation," Pharmaceuticals, 2022, doi: 10.3390/ph15020254.
20. M. K. Remanan and F. Zhu, "Encapsulation of rutin in Pickering emulsions stabilized using octenyl succinic anhydride (OSA) modified quinoa, maize, and potato starch nanoparticles," Food Chem., 2023, doi: 10.1016/j.foodchem.2022.134790.
21. N. Ahmad et al., "Rutin-encapsulated chitosan nanoparticles targeted to the brain in the treatment of Cerebral Ischemia," Int. J. Biol.

Macromol., 2016, doi: 10.1016/j.ijbiomac.2016.06.001.
22. A. Gagliardi, D. Paolino, N. Costa, M. Fresta, and D. Cosco, "Zein- vs PLGA-based nanoparticles containing rutin: A comparative investigation," Mater. Sci. Eng. C, 2021, doi: 10.1016/j.msec.2020.111538.
23. C. Li et al., "Preparation and Characterization of Rutin–Loaded Zein–Carboxymethyl Starch Nanoparticles," Foods, 2022, doi: 10.3390/foods11182827.
24. C. G. Chilom et al., "Albumin–Rutin Nanoparticles: Design, Characterization, and Biophysical Evaluation," Coatings, 2024, doi: 10.3390/coatings14020220.
25. M. H. Alqarni et al., "Development of Gum-Acacia-Stabilized Silver Nanoparticles Gel of Rutin against Candida albicans," Gels, 2022, doi: 10.3390/gels8080472.
26. K. R. Paudel et al., "Rutin loaded liquid crystalline nanoparticles inhibit non-small cell lung cancer proliferation and migration in vitro," Life Sci., 2021, doi: 10.1016/j.lfs.2021.119436.
27. K. K. Moravkar et al., "Extraction of rutin from tagetes erecta (Marigold) and preparation of peroral nano-suspension for effective antitussive/expectorant therapy," Carbohydr. Polym. Technol. Appl., 2023, doi: 10.1016/j.carpta.2023.100320.
28. K. M. Mohamed et al., "Rutin-loaded selenium nanoparticles modulated the redox status, inflammatory, and apoptotic pathways associated with pentylenetetrazole-induced epilepsy in mice," Green Process. Synth., 2023, doi: 10.1515/gps-2023-0010.
29. A. Shandil et al., "Targeting keratinocyte hyperproliferation, inflammation, oxidative species and microbial infection by biological macromolecule-based chitosan nanoparticle-mediated gallic acid–rutin combination for the treatment of psoriasis," Polym. Bull., 2020, doi: 10.1007/s00289-019-02984-9.
30. M. Y. Memar, E. Dalir Abdolahinia, M. Yekani, M. Kouhsoltani, S. Sharifi, and S. Maleki Dizaj, "Preparation of rutin-loaded mesoporous silica nanoparticles and evaluation of its physicochemical, anticancer, and antibacterial properties," Mol. Biol. Rep., 2023, doi: 10.1007/s11033-022-07953-6.
31. N. M. Wahed, M. Abomosallam, B. M. Hendam, Z. Shouman, N. M. A. Hashem, and S. A. Sakr, "Economic and Productive Comparison of Rutin and Rutin-Loaded Chitosan Alginate Nanoparticles Against Lead-Induced Oxidative Stress in Cobb and Arbor Broiler Breeds," Biol. Trace Elem. Res., 2024, doi: 10.1007/s12011-023-04019-x.
32. K. R. Paudel, R. Wadhwa, M. Mehta, D. K. Chellappan, P. M. Hansbro, and K. Dua, "Rutin loaded liquid crystalline nanoparticles inhibit lipopolysaccharide induced oxidative stress and apoptosis in bronchial epithelial cells in vitro," Toxicol. Vitr., 2020, doi: 10.1016/j.tiv.2020.104961.
33. T. KİRİK and K. KIZILBEY, "Rutin yüklü PLGA Nanopartiküller; Farklı Yöntemler Kullanılarak Sentezi ve Karakterizasyonu," Iğdır Üniversitesi Fen Bilim. Enstitüsü Derg., 2019, doi: 10.21597/jist.481180.
34. V. Surendran and N. N. Palei, "Formulation and Characterization of Rutin Loaded Chitosan-alginate Nanoparticles: Antidiabetic and Cytotoxicity Studies," Curr. Drug Deliv., 2021, doi: 10.2174/1567201818666211005090656.
35. A. Júlio et al., "Ionic liquid-polymer nanoparticle hybrid systems as new tools to deliver poorly soluble drugs," Nanomaterials, 2019, doi: 10.3390/nano9081148.
36. P. Dahiya, A. Zafar, F. J. Ahmad, M. Khalid, and A. Ali, "Development of Forskolin and rutin-loaded polymeric nanoparticles for enhancement of topical ocular delivery: Optimization, in-vitro, ex-vivo, and toxicity evaluation," J. Drug Deliv. Sci. Technol., 2023, doi: 10.1016/j.jddst.2023.104292.
37. Y. Guo et al., "Preparation of Rutin-liposome Drug Delivery Systems and Evaluation on Their in vitro Antioxidant Activity," Chinese Herb. Med., 2016, doi: 10.1016/s1674-6384(16)60065-5.
38. V. Kumar, R. Kharb, and H. Chaudhary, "Optimization & design of isradipine loaded solid lipid nanobioparticles using rutin by Taguchi methodology," Int. J. Biol. Macromol., 2016, doi: 10.1016/j.ijbiomac.2016.07.020.
39. K. Singh et al., "Deciphering the Genetic Landscape: Exploring the Relationship Between HLA-DQA1, HLA-DQB1, and HLA-DRB1 Genes in Diabetes Mellitus," Curr. Pharmacogenomics Person. Med., vol. 21, pp. 1–11, 2024, doi: 10.2174/0118756921310081240821065036.
40. S. Pozos-Nonato et al., "Novel Nanotechnological Strategies for Skin Anti-aging," Curr. Pharm. Biotechnol., 2022, doi: 10.2174/1389201024666221223095315.
41. Senthil Kumar C, Moorthi C, Sundararajan N, Sivasakthi R, and Mohan S, "Formulation and Evaluation of Duo Flavono Loaded Anionic Polymeric Nanoparticulate System," Int. J. Res. Pharm. Sci., 2021, doi: 10.26452/ijrps.v12i1.4117.
42. R. A. H. Ishak, N. M. Mostafa, and A. O. Kamel, "Stealth lipid polymer hybrid nanoparticles loaded with rutin for effective brain delivery – comparative study with the gold standard (Tween 80): Optimization, characterization and biodistribution," Drug Deliv., 2017, doi: 10.1080/10717544.2017.1410263.
43. T. Ali, "Chromatography and Spectroscopic Characterization of Nano-Carrier Pharmaceuticals," Pharm. Nanotechnol., 2024, doi: 10.2174/0122117385319695240911115239.
44. I. Dammak, R. A. de Carvalho, C. S. F. Trindade, R. V. Lourenço, and P. J. do Amaral Sobral, "Properties of active gelatin films incorporated with rutin-loaded nanoemulsions," Int. J. Biol. Macromol., 2017, doi: 10.1016/j.ijbiomac.2017.01.094.
45. A. Kajbafvala and A. Salabat, "Microemulsion and microemulsion gel formulation for transdermal delivery of rutin: Optimization, in-vitro/ex-vivo evaluation and SPF determination," J. Dispers. Sci. Technol., 2022, doi: 10.1080/01932691.2021.1880928.
46. T. F. Rakotondrabe, M. X. Fan, F. W. Muema, and

M. Q. Guo, "Modulating Inflammation-Mediated Diseases via Natural Phenolic Compounds Loaded in Nanocarrier Systems," 2023. doi: 10.3390/pharmaceutics15020699.
47. A. K. Jaiswal et al., "Multi-targeted therapeutic exploration of Tamarix gallica flowers for anti-ulcer activity and associated complications," J. Ayurveda Integr. Med., vol. 15, no. 4, p. 100947, 2024, doi: 10.1016/j.jaim.2024.100947.
48. R. Ibrahim, V. Kasabri, S. Sunoqrot, D. Shalabi, R. Alkhateeb, and Y. Alhiari, "Preparation and Characterization of Rutin-Encapsulated Polymeric Micelles and Studies of Synergism with Bioactive Benzoic Acids and Triazolofluoroquinolones as Anticancer Nanomedicines," Asian Pacific J. Cancer Prev., 2023, doi: 10.31557/APJCP.2023.24.3.977.
49. J. Chen et al., "Multilayer Ti3C2-CNTs-Au Loaded with Cyclodextrin-MOF for Enhanced Selective Detection of Rutin," Small, 2024, doi: 10.1002/smll.202310217.
50. Y. Sharma et al., "Nano-gel formulation of polyphenolic fraction of tobacco stem for wound healing and its inhibitory efficacies against the receptors of chronic wound development," J. Biomol. Struct. Dyn., 2024, doi: 10.1080/07391102.2024.2317986.
51. H. Zahmatkesh, F. Esnaashari, and H. Zamani, "Inhibition of Virulence Properties of Pathogenic Pseudomonas aeruginosa by Rutin-Loaded Chitosan Nanoparticles," J. Clust. Sci., 2024, doi: 10.1007/s10876-023-02535-3.
52. P. Pandey et al., "Implication of nano-antioxidant therapy for treatment of hepatocellular carcinoma using PLGA nanoparticles of rutin," Nanomedicine, 2018, doi: 10.2217/nnm-2017 0306.
53. T. Thi Hai Yen, H. Thi Hien, and V. Thi Thu Giang, "Preparation of Nano Niosomes Loaded with Rutin and Aloe Gel Extract," VNU J. Sci. Med. Pharm. Sci., 2020, doi: 10.25073/2588-1132/vnumps.4208.
54. C. A. De Oliveira et al., "Cutaneous biocompatible rutin-loaded gelatin-based nanoparticles increase the SPF of the association of UVA and UVB filters," Eur. J. Pharm. Sci., 2016, doi: 10.1016/j.ejps.2015.09.016.
55. A. Kirthi Bhushan, D. N. Ammunje, S. Kunjiappan, A. Jayaraman, M. Devi, and P. Pavadai, "An in-Silico approach to evaluate the binding efficacy and stability profile of MWCNT entangled rutin for breast cancer treatment," Nanomedicine J., 2023, doi: 10.22038/NMJ.2023.70663.1756.
56. R. G. Kerry et al., "Biosynthesis of Rutin Trihydrate Loaded Silica Nanoparticles and Investigation of Its Antioxidant, Antidiabetic and Cytotoxic Potentials," J. Inorg. Organomet. Polym. Mater., 2022, doi: 10.1007/s10904-022-02269-1.
57. Z. Hooresfand, S. Ghanbarzadeh, and H. Hamishehkar, "Preparation and characterization of rutin-loaded nanophytosomes," Pharm. Sci., 2015, doi: 10.15171/PS.2015.29.
58. S. Zhang and Y. Han, "Preparation, characterisation and antioxidant activities of rutin-loaded zein-sodium caseinate nanoparticles," PLoS One, 2018, doi: 10.1371/journal.pone.0194951.
59. X. Xia et al., "Antibacterial and anti-inflammatory ZIF-8@Rutin nanocomposite as an efficient agent for accelerating infected wound healing," Front. Bioeng. Biotechnol., 2022, doi: 10.3389/fbioe.2022.1026743.
60. V. Sokolova and M. Epple, "Biological and Medical Applications of Calcium Phosphate Nanoparticles," 2021. doi: 10.1002/chem.202005257.
61. M. Rodriguez, Y. Soler, M. K. M. Karuppan, Y. Zhao, E. V. Batrakova, and N. El-Hage, "Targeting beclin1 as an adjunctive therapy against hiv using mannosylated polyethylenimine nanoparticles," Pharmaceutics, 2021, doi: 10.3390/pharmaceutics13020223.
62. Q. Feng, B. Fan, Y. C. He, and C. Ma, "Antibacterial, antioxidant and fruit packaging ability of biochar-based silver nanoparticles-polyvinyl alcohol-chitosan composite film," Int. J. Biol. Macromol., 2024, doi: 10.1016/j.ijbiomac.2023.128297.
63. A. Dey et al., "State of the Art and Prospects for Halide Perovskite Nanocrystals," 2021. doi: 10.1021/acsnano.0c08903.
64. H. Elmotasem and G. E. A. Awad, "A stepwise optimization strategy to formulate in situ gelling formulations comprising fluconazole-hydroxypropyl-beta-cyclodextrin complex loaded niosomal vesicles and Eudragit nanoparticles for enhanced antifungal activity and prolonged ocular delivery," Asian J. Pharm. Sci., 2020, doi: 10.1016/j.ajps.2019.09.003.
65. A. Jayachandran, A. T.R., and A. S. Nair, "Green synthesis and characterization of zinc oxide nanoparticles using Cayratia pedata leaf extract," Biochem. Biophys. Reports, 2021, doi: 10.1016/j.bbrep.2021.100995.
66. L. Zerrillo et al., "Novel fluorinated poly (Lactic-co-glycolic acid) (plga) and polyethylene glycol (peg) nanoparticles for monitoring and imaging in osteoarthritis," Pharmaceutics, 2021, doi: 10.3390/pharmaceutics13020235.
67. G. Antarnusa and E. Suharyadi, "A synthesis of polyethylene glycol (PEG)-coated magnetite Fe3O4 nanoparticles and their characteristics for enhancement of biosensor," Mater. Res. Express, 2020, doi: 10.1088/2053-1591/ab8bef.
68. S. Cesur, "Combination techniques towards novel drug delivery systems manufacturing: 3D PCL scaffolds enriched with tetracycline-loaded PVP nanoparticles," Eur. J. Pharm. Biopharm., 2024, doi: 10.1016/j.ejpb.2023.11.022.
69. M. Arkas et al., "Catalytic Neutralization of Water Pollutants Mediated by Dendritic Polymers," 2022. doi: 10.3390/nano12030445.
70. K. Zhang et al., "Physicochemical and functional properties of chitosan-based edible film incorporated with Sargassum pallidum polysaccharide nanoparticles," Food Hydrocoll., 2023, doi: 10.1016/j.foodhyd.2023.108476.
71. X. Zhuang et al., "MRNA vaccines encoding the HA protein of influenza a H1N1 virus delivered by cationic lipid nanoparticles induce protective immune responses in mice," Vaccines, 2020, doi: 10.3390/vaccines8010123.
72. A. Aijaz, D. A. Raja, F. A. Khan, J. Barek, and M. I.

Malik, “A Silver Nanoparticles-Based Selective and Sensitive Colorimetric Assay for Ciprofloxacin in Biological, Environmental, and Commercial Samples,” Chemosensors, 2023, doi: 10.3390/chemosensors11020091.
73. A. I. Fahira, R. Abdulah, M. I. Barliana, V. A. Gatera, and R. Amalia, “Polyethyleneimine (PEI) as a Polymer-Based Co-Delivery System for Breast Cancer Therapy,” 2022. doi: 10.2147/BCTT.S350403.
74. L. Qiu et al., “Preparation and properties of allyl ether-based polycarboxylate superplasticizer with short-branched chains modified by nano-silica,” J. Chem. Res., 2022, doi: 10.1177/17475198221091903.
75. L. Mahawar et al., “Silicon nanoparticles: Comprehensive review on biogenic synthesis and applications in agriculture,” Environ. Res., 2023, doi: 10.1016/j.envres.2023.116292.
76. X. Chen et al., “Influence of Elasticity of Hydrogel Nanoparticles on Their Tumor Delivery,” Adv. Sci., 2022, doi: 10.1002/advs.202202644.
77. F. B. Ilhami, E. Erman, A. Rahmawati, Y. S. Birhan, Fitriana, and A. H. Tiwikrama, “Self-assembled supramolecular nanoparticle by host-guest interaction for thermo-controlled released of magnolol in cancer chemotherapy,” J. Drug Deliv. Sci. Technol., 2023, doi: 10.1016/j.jddst.2023.105078.
78. M. G. Giordano, G. Seganti, M. Bartoli, and A. Tagliaferro, “An Overview on Carbon Quantum Dots Optical and Chemical Features,” 2023. doi: 10.3390/molecules28062772.
79. S. Soni et al., “Herbal nanogels: Revolutionizing skin cancer therapy through nanotechnology and natural remedies,” Eur. J. Med. Chem. Reports, 2024, doi: 10.1016/j.ejmcr.2023.100126.
80. H. Nsairat, D. Khater, U. Sayed, F. Odeh, A. Al Bawab, and W. Alshaer, “Liposomes: structure, composition, types, and clinical applications,” 2022. doi: 10.1016/j.heliyon.2022.e09394.
81. W. C. Luo and X. Lu, “Solid Lipid Nanoparticles for Drug Delivery,” Methods Mol. Biol., 2023, doi: 10.1007/978-1-0716-2954-3_12.
82. M. Elmowafy et al., “Polymeric Nanoparticles for Delivery of Natural Bioactive Agents: Recent Advances and Challenges,” 2023. doi: 10.3390/polym15051123.
83. D. Zhang, X. L. Ma, Y. Gu, H. Huang, and G. W. Zhang, “Green Synthesis of Metallic Nanoparticles and Their Potential Applications to Treat Cancer,” 2020. doi: 10.3389/fchem.2020.00799.
84. E. B. Souto, A. Cano, C. Martins-Gomes, T. E. Coutinho, A. Zielińska, and A. M. Silva, “Microemulsions and Nanoemulsions in Skin Drug Delivery,” 2022. doi: 10.3390/bioengineering9040158.
85. S. A. Alkahtani, A. M. Mahmoud, Y. S. Alqahtani, A. M. B. H. Ali, and M. M. El-Wekil, “Selective detection of rutin at novel pyridinic-nitrogen-rich carbon dots derived from chicken feet biowaste: The role of bovine serum albumin during the assay,” Spectrochim. Acta - Part A Mol. Biomol. Spectrosc., 2023, doi: 10.1016/j.saa.2023.123252.
86. D. Liu, Y. Zhao, J. Ji, X. Liu, S. Feng, and X. Chen, “Design of fluorescence system based on rutin functionalized gold nanoparticles: Sensitive detection of etimicin via a smartphone in the food and human samples,” Arab. J. Chem., 2022, doi: 10.1016/j.arabjc.2022.104325.
87. Z. Nouri, S. Fakhri, K. Nouri, C. E. Wallace, M. H. Farzaei, and A. Bishayee, “Targeting multiple signaling pathways in cancer: The rutin therapeutic approach,” 2020. doi: 10.3390/cancers12082276.
88. H. Qanash et al., “Phytochemical Characterization and Efficacy of Artemisia judaica Extract Loaded Chitosan Nanoparticles as Inhibitors of Cancer Proliferation and Microbial Growth,” Polymers (Basel)., 2023, doi: 10.3390/polym15020391.
89. A. O. Falade et al., “Aqueous Extracts of Bay Leaf (Laurus nobilis) and Rosemary (Rosmarinus officinalis) Inhibit Iron-Induced Lipid Peroxidation and Key-Enzymes Implicated in Alzheimer’s Disease in Rat Brain-in Vitro,” Am. J. Biochem. Biotechnol., 2022, doi: 10.3844/ajbbsp.2022.9.22.
90. M. M. Kher, M. S. Shekhawat, M. Nataraj, and J. A. Teixeira da Silva, “Indian sarsaparilla, Hemidesmus indicus (L.) R. Br. ex Schult: tissue culture studies,” 2020. doi: 10.1007/s00253-020-10714-9.
91. R. Saha, S. Patkar, M. M. Pillai, and P. Tayalia, “Bilayered skin substitute incorporating rutin nanoparticles for antioxidant, anti-inflammatory, and anti-fibrotic effect,” Biomater. Adv., 2023, doi: 10.1016/j.bioadv.2023.213432.
92. S. Saha and A. Mishra, “A facile preparation of rutin nanoparticles and its effects on controlled growth and morphology of calcium oxalate crystals,” J. Cryst. Growth, 2020, doi: 10.1016/j.jcrysgro.2020.125635.
93. H. Wu et al., “Rutin-Loaded Silver Nanoparticles With Antithrombotic Function,” Front. Bioeng. Biotechnol., 2020, doi: 10.3389/fbioe.2020.598977.
94. S. Luo, Y. Fu, J. Ye, and C. Liu, “Encapsulation of rutin in protein nanoparticles by pH-driven method: impact of rutin solubility and mechanisms,” J. Sci. Food Agric., 2024, doi: 10.1002/jsfa.13068.
95. H. T. H. Vu, S. Streck, S. M. Hook, and A. McDowell, “Utilization of Microfluidics for the Preparation of Polymeric Nanoparticles for the Antioxidant Rutin: A Comparison with Bulk Production,” Pharm. Nanotechnol., 2019, doi: 10.2174/2211738507666191019141049.
96. R. C. Pedrozo, E. Antônio, N. M. Khalil, and R. M. Mainardes, “Bovine serum albumin–based nanoparticles containing the flavonoid rutin produced by nano spray drying,” Brazilian J. Pharm. Sci., 2020, doi: 10.1590/s2175-97902019000317692.
97. K. Kizilbey, “Optimization of Rutin-Loaded PLGA Nanoparticles Synthesized by Single-Emulsion Solvent Evaporation Method,” ACS Omega, 2019, doi: 10.1021/acsomega.8b02767.
98. M. R. Khan, D. Kumar, S. Shamim, K. Sunand, S. Sharma, and G. Rawat, “Ethnopharmacological relevance of Citrus limon (L.) Burm. f. as adjuvant therapy,” Ann. Phytomedicine An Int. J., vol. 12, no. 2, pp. 169–179, 2023, doi:

10.54085/ap.2023.12.2.19.
99. M. J. dos Santos Alves et al., “Starch nanoparticles containing phenolic compounds from green propolis: Characterization and evaluation of antioxidant, antimicrobial and digestibility properties,” Int. J. Biol. Macromol., 2024, doi: 10.1016/j.ijbiomac.2023.128079.
100. E. Tobar-Delgado, D. Mejía-España, O. Osorio-Mora, and L. Serna-Cock, “Rutin: Family Farming Products’ Extraction Sources, Industrial Applications and Current Trends in Biological Activity Protection,” 2023. doi: 10.3390/molecules28155864.
101. S. Ilbasmis-Tamer, E. S. Saral-Acarca, S. Tort, Ç. Yücel, U. Tamer, and F. Acartürk, “Fabrication and characterization of starch-copper nanoparticles/rutin nanofiber hybrid scaffold,” J. Drug Deliv. Sci. Technol., 2022, doi: 10.1016/j.jddst.2022.103401.
102. M. G. Raju, M. Srivani, N. V. L. Suvarchala Reddy, and G. S. Priya, “Formulation and Characterization of Rutin Loaded Chitosan Nanoparticles,” Asian J. Res. Med. Pharm. Sci., 2022, doi: 10.9734/ajrimps/2022/v11i130180.
103. [13] S. A. Ali, S. Ali, S. Rastogi, B. Shivhare, and M. Muztaba, “A Comprehensive Review on Advancements in Nanocarriers-Based Peptide Delivery for Cancer Therapeutics,” Micro Nanosyst., vol. 17, no. 4, pp. 283–297, 2025, doi: 10.2174/0118764029358553250325040749.
104. G. Kamaris, A. Dalavitsou, and C. K. Markopoulou, “Development and Validation of an HPLC-DAD Method for the Determination of Seven Antioxidants in a Nano-Emulsion: Formulation and Stability Study,” Separations, 2024, doi: 10.3390/separations11020043.
105. A. Hedayati, F. Naseri, E. Nourozi, B. Hosseini, H. Honari, and S. Hemmaty, “Response of Saponaria officinalis L. hairy roots to the application of TiO2 nanoparticles in terms of production of valuable polyphenolic compounds and SO6 protein,” Plant Physiol. Biochem., 2022, doi: 10.1016/j.plaphy.2022.03.001.
106. Sutrino, “Pengaruh Pelatihan Kerja, Kompetensi Sdm Dan Motivasi Kerja Terhadap Kinerja Karyawan Pada Ud Afalia Jaya Tumpang Malang,” Molecules, 2019.
107. M. Mendoza and O. Rodríguez, “COMPARACIÓN DE PARÁMETROS FÍSICO-QUÍMICOS DE COMPRIMIDOS DE CARVEDILOL DE 25MG GENÉRICO FRENTE AL MEDICAMENTO INNOVADOR,” Molecules, 2022.
108. A. Kinicki and M. Fugate, “Organizational behavior,” McGraw Hill Educ., 2020.
109. W. Eaknai et al., “Ethanolic Fenugreek Extract: Its Molecular Mechanisms against Skin Aging and the Enhanced Functions by Nanoencapsulation,” Pharmaceuticals, 2022, doi: 10.3390/ph15020254.
110. M. K. Remanan and F. Zhu, “Encapsulation of rutin in Pickering emulsions stabilized using octenyl succinic anhydride (OSA) modified quinoa, maize, and potato starch nanoparticles,” Food Chem., 2023, doi: 10.1016/j.foodchem.2022.134790.
111. N. Ahmad et al., “Rutin-encapsulated chitosan nanoparticles targeted to the brain in the treatment of Cerebral Ischemia,” Int. J. Biol. Macromol., 2016, doi: 10.1016/j.ijbiomac.2016.06.001.
112. A. Gagliardi, D. Paolino, N. Costa, M. Fresta, and D. Cosco, “Zein- vs PLGA-based nanoparticles containing rutin: A comparative investigation,” Mater. Sci. Eng. C, 2021, doi: 10.1016/j.msec.2020.111538.
113. C. Li et al., “Preparation and Characterization of Rutin–Loaded Zein–Carboxymethyl Starch Nanoparticles,” Foods, 2022, doi: 10.3390/foods11182827.
114. C. G. Chilom et al., “Albumin–Rutin Nanoparticles: Design, Characterization, and Biophysical Evaluation,” Coatings, 2024, doi: 10.3390/coatings14020220.
115. M. H. Alqarni et al., “Development of Gum-Acacia-Stabilized Silver Nanoparticles Gel of Rutin against Candida albicans,” Gels, 2022, doi: 10.3390/gels8080472.
116. K. R. Paudel et al., “Rutin loaded liquid crystalline nanoparticles inhibit non-small cell lung cancer proliferation and migration in vitro,” Life Sci., 2021, doi: 10.1016/j.lfs.2021.119436.
117. K. K. Moravkar et al., “Extraction of rutin from tagetes erecta (Marigold) and preparation of peroral nano-suspension for effective antitussive/expectorant therapy,” Carbohydr. Polym. Technol. Appl., 2023, doi: 10.1016/j.carpta.2023.100320.
118. K. M. Mohamed et al., “Rutin-loaded selenium nanoparticles modulated the redox status, inflammatory, and apoptotic pathways associated with pentylenetetrazole-induced epilepsy in mice,” Green Process. Synth., 2023, doi: 10.1515/gps-2023-0010.
119. A. Shandil et al., “Targeting keratinocyte hyperproliferation, inflammation, oxidative species and microbial infection by biological macromolecule-based chitosan nanoparticle-mediated gallic acid–rutin combination for the treatment of psoriasis,” Polym. Bull., 2020, doi: 10.1007/s00289-019-02984-9.
120. M. Y. Memar, E. Dalir Abdolahinia, M. Yekani, M. Kouhsoltani, S. Sharifi, and S. Maleki Dizaj, “Preparation of rutin-loaded mesoporous silica nanoparticles and evaluation of its physicochemical, anticancer, and antibacterial properties,” Mol. Biol. Rep., 2023, doi: 10.1007/s11033-022-07953-6.
121. N. M. Wahed, M. Abomosallam, B. M. Hendam, Z. Shouman, N. M. A. Hashem, and S. A. Sakr, “Economic and Productive Comparison of Rutin and Rutin-Loaded Chitosan Alginate Nanoparticles Against Lead-Induced Oxidative Stress in Cobb and Arbor Broiler Breeds,” Biol. Trace Elem. Res., 2024, doi: 10.1007/s12011-023-04019-x.
122. K. R. Paudel, R. Wadhwa, M. Mehta, D. K. Chellappan, P. M. Hansbro, and K. Dua, “Rutin loaded liquid crystalline nanoparticles inhibit lipopolysaccharide induced oxidative stress and apoptosis in bronchial epithelial cells in vitro,” Toxicol. Vitr., 2020, doi: 10.1016/j.tiv.2020.104961.

123. T. KİRİK and K. KIZILBEY, “Rutin yüklü PLGA Nanopartiküller; Farklı Yöntemler Kullanılarak Sentezi ve Karakterizasyonu,” Iğdır Üniversitesi Fen Bilim. Enstitüsü Derg., 2019, doi: 10.21597/jist.481180.
124. V. Surendran and N. N. Palei, “Formulation and Characterization of Rutin Loaded Chitosan-alginate Nanoparticles: Antidiabetic and Cytotoxicity Studies,” Curr. Drug Deliv., 2021, doi: 10.2174/1567201818666211005090656.
125. A. Júlio et al., “Ionic liquid-polymer nanoparticle hybrid systems as new tools to deliver poorly soluble drugs,” Nanomaterials, 2019, doi: 10.3390/nano9081148.
126. P. Dahiya, A. Zafar, F. J. Ahmad, M. Khalid, and A. Ali, “Development of Forskolin and rutin-loaded polymeric nanoparticles for enhancement of topical ocular delivery: Optimization, in-vitro, ex-vivo, and toxicity evaluation,” J. Drug Deliv. Sci. Technol., 2023, doi: 10.1016/j.jddst.2023.104292.
127. Y. Guo et al., “Preparation of Rutin-liposome Drug Delivery Systems and Evaluation on Their in vitro Antioxidant Activity,” Chinese Herb. Med., 2016, doi: 10.1016/s1674-6384(16)60065-5.
128. V. Kumar, R. Kharb, and H. Chaudhary, “Optimization & design of isradipine loaded solid lipid nanobioparticles using rutin by Taguchi methodology,” Int. J. Biol. Macromol., 2016, doi: 10.1016/j.ijbiomac.2016.07.020.
129. K. Singh et al., “Deciphering the Genetic Landscape: Exploring the Relationship Between HLA-DQA1, HLA-DQB1, and HLA-DRB1 Genes in Diabetes Mellitus,” Curr. Pharmacogenomics Person. Med., vol. 21, pp. 1–11, 2024, doi: 10.2174/0118756921310081240821065036.
130. S. Pozos-Nonato et al., “Novel Nanotechnological Strategies for Skin Anti-aging,” Curr. Pharm. Biotechnol., 2022, doi: 10.2174/1389201024666221223095315.
131. Senthil Kumar C, Moorthi C, Sundararajan N, Sivasakthi R, and Mohan S, “Formulation and Evaluation of Duo Flavono Loaded Anionic Polymeric Nanoparticulate System,” Int. J. Res. Pharm. Sci., 2021, doi: 10.26452/ijrps.v12i1.4117.
132. R. A. H. Ishak, N. M. Mostafa, and A. O. Kamel, “Stealth lipid polymer hybrid nanoparticles loaded with rutin for effective brain delivery – comparative study with the gold standard (Tween 80): Optimization, characterization and biodistribution,” Drug Deliv., 2017, doi: 10.1080/10717544.2017.1410263.
133. T. Ali, “Chromatography and Spectroscopic Characterization of Nano-Carrier Pharmaceuticals,” Pharm. Nanotechnol., 2024, doi: 10.2174/0122117385319695240911115239.
134. I. Dammak, R. A. de Carvalho, C. S. F. Trindade, R. V. Lourenço, and P. J. do Amaral Sobral, “Properties of active gelatin films incorporated with rutin-loaded nanoemulsions,” Int. J. Biol. Macromol., 2017, doi: 10.1016/j.ijbiomac.2017.01.094.
135. A. Kajbafvala and A. Salabat, “Microemulsion and microemulsion gel formulation for transdermal delivery of rutin: Optimization, in-vitro/ex-vivo evaluation and SPF determination,” J. Dispers. Sci. Technol., 2022, doi: 10.1080/01932691.2021.1880928.
136. T. F. Rakotondrabe, M. X. Fan, F. W. Muema, and M. Q. Guo, “Modulating Inflammation-Mediated Diseases via Natural Phenolic Compounds Loaded in Nanocarrier Systems,” 2023. doi: 10.3390/pharmaceutics15020699.
137. A. K. Jaiswal et al., “Multi-targeted therapeutic exploration of Tamarix gallica flowers for anti-ulcer activity and associated complications,” J. Ayurveda Integr. Med., vol. 15, no. 4, p. 100947, 2024, doi: 10.1016/j.jaim.2024.100947.
138. R. Ibrahim, V. Kasabri, S. Sunoqrot, D. Shalabi, R. Alkhateeb, and Y. Alhiari, “Preparation and Characterization of Rutin-Encapsulated Polymeric Micelles and Studies of Synergism with Bioactive Benzoic Acids and Triazolofluoroquinolones as Anticancer Nanomedicines,” Asian Pacific J. Cancer Prev., 2023, doi: 10.31557/APJCP.2023.24.3.977.
139. J. Chen et al., “Multilayer Ti3C2-CNTs-Au Loaded with Cyclodextrin-MOF for Enhanced Selective Detection of Rutin,” Small, 2024, doi: 10.1002/smll.202310217.
140. Y. Sharma et al., “Nano-gel formulation of polyphenolic fraction of tobacco stem for wound healing and its inhibitory efficacies against the receptors of chronic wound development,” J. Biomol. Struct. Dyn., 2024, doi: 10.1080/07391102.2024.2317986.
141. H. Zahmatkesh, F. Esnaashari, and H. Zamani, “Inhibition of Virulence Properties of Pathogenic Pseudomonas aeruginosa by Rutin-Loaded Chitosan Nanoparticles,” J. Clust. Sci., 2024, doi: 10.1007/s10876-023-02535-3.
142. P. Pandey et al., “Implication of nano-antioxidant therapy for treatment of hepatocellular carcinoma using PLGA nanoparticles of rutin,” Nanomedicine, 2018, doi: 10.2217/nnm-2017-0306.
143. T. Thi Hai Yen, H. Thi Hien, and V. Thi Thu Giang, “Preparation of Nano Niosomes Loaded with Rutin and Aloe Gel Extract,” VNU J. Sci. Med. Pharm. Sci., 2020, doi: 10.25073/2588-1132/vnumps.4208.
144. C. A. De Oliveira et al., “Cutaneous biocompatible rutin-loaded gelatin-based nanoparticles increase the SPF of the association of UVA and UVB filters,” Eur. J. Pharm. Sci., 2016, doi: 10.1016/j.ejps.2015.09.016.
145. A. Kirthi Bhushan, D. N. Ammunje, S. Kunjiappan, A. Jayaraman, M. Devi, and P. Pavadai, “An in-Silico approach to evaluate the binding efficacy and stability profile of MWCNT entangled rutin for breast cancer treatment,” Nanomedicine J., 2023, doi: 10.22038/NMJ.2023.70663.1756.
146. R. G. Kerry et al., “Biosynthesis of Rutin Trihydrate Loaded Silica Nanoparticles and Investigation of Its Antioxidant, Antidiabetic and Cytotoxic Potentials,” J. Inorg. Organomet. Polym. Mater., 2022, doi: 10.1007/s10904-022-02269-1.
147. Z. Hooresfand, S. Ghanbarzadeh, and H. Hamishehkar, “Preparation and characterization of rutin-loaded nanophytosomes,” Pharm. Sci., 2015, doi: 10.15171/PS.2015.29.
148. S. Zhang and Y. Han, “Preparation, characterisation and antioxidant activities of rutin-

loaded zein-sodium caseinate nanoparticles," PLoS One, 2018, doi: 10.1371/journal.pone.0194951.
149. X. Xia et al., "Antibacterial and anti-inflammatory ZIF-8@Rutin nanocomposite as an efficient agent for accelerating infected wound healing," Front. Bioeng. Biotechnol., 2022, doi: 10.3389/fbioe.2022.1026743.
150. V. Sokolova and M. Epple, "Biological and Medical Applications of Calcium Phosphate Nanoparticles," 2021. doi: 10.1002/chem.202005257.
151. M. Rodriguez, Y. Soler, M. K. M. Karuppan, Y. Zhao, E. V. Batrakova, and N. El-Hage, "Targeting beclin1 as an adjunctive therapy against hiv using mannosylated polyethylenimine nanoparticles," Pharmaceutics, 2021, doi: 10.3390/pharmaceutics13020223.
152. Q. Feng, B. Fan, Y. C. He, and C. Ma, "Antibacterial, antioxidant and fruit packaging ability of biochar-based silver nanoparticles-polyvinyl alcohol-chitosan composite film," Int. J. Biol. Macromol., 2024, doi: 10.1016/j.ijbiomac.2023.128297.
153. A. Dey et al., "State of the Art and Prospects for Halide Perovskite Nanocrystals," 2021. doi: 10.1021/acsnano.0c08903.
154. H. Elmotasem and G. E. A. Awad, "A stepwise optimization strategy to formulate in situ gelling formulations comprising fluconazole-hydroxypropyl-beta-cyclodextrin complex loaded niosomal vesicles and Eudragit nanoparticles for enhanced antifungal activity and prolonged ocular delivery," Asian J. Pharm. Sci., 2020, doi: 10.1016/j.ajps.2019.09.003.
155. A. Jayachandran, A. T.R., and A. S. Nair, "Green synthesis and characterization of zinc oxide nanoparticles using Cayratia pedata leaf extract," Biochem. Biophys. Reports, 2021, doi: 10.1016/j.bbrep.2021.100995.
156. L. Zerrillo et al., "Novel fluorinated poly (Lactic-co-glycolic acid) (plga) and polyethylene glycol (peg) nanoparticles for monitoring and imaging in osteoarthritis," Pharmaceutics, 2021, doi: 10.3390/pharmaceutics13020235.
157. G. Antarnusa and E. Suharyadi, "A synthesis of polyethylene glycol (PEG)-coated magnetite Fe3O4 nanoparticles and their characteristics for enhancement of biosensor," Mater. Res. Express, 2020, doi: 10.1088/2053-1591/ab8bef.
158. S. Cesur, "Combination techniques towards novel drug delivery systems manufacturing: 3D PCL scaffolds enriched with tetracycline-loaded PVP nanoparticles," Eur. J. Pharm. Biopharm., 2024, doi: 10.1016/j.ejpb.2023.11.022.
159. M. Arkas et al., "Catalytic Neutralization of Water Pollutants Mediated by Dendritic Polymers," 2022. doi: 10.3390/nano12030445.
160. K. Zhang et al., "Physicochemical and functional properties of chitosan-based edible film incorporated with Sargassum pallidum polysaccharide nanoparticles," Food Hydrocoll., 2023, doi: 10.1016/j.foodhyd.2023.108476.
161. X. Zhuang et al., "MRNA vaccines encoding the HA protein of influenza a H1N1 virus delivered by cationic lipid nanoparticles induce protective immune responses in mice," Vaccines, 2020, doi: 10.3390/vaccines8010123.
162. A. Aijaz, D. A. Raja, F. A. Khan, J. Barek, and M. I. Malik, "A Silver Nanoparticles-Based Selective and Sensitive Colorimetric Assay for Ciprofloxacin in Biological, Environmental, and Commercial Samples," Chemosensors, 2023, doi: 10.3390/chemosensors11020091.
163. A. I. Fahira, R. Abdulah, M. I. Barliana, V. A. Gatera, and R. Amalia, "Polyethyleneimine (PEI) as a Polymer-Based Co-Delivery System for Breast Cancer Therapy," 2022. doi: 10.2147/BCTT.S350403.
164. L. Qiu et al., "Preparation and properties of allyl ether-based polycarboxylate superplasticizer with short-branched chains modified by nano-silica," J. Chem. Res., 2022, doi: 10.1177/17475198221091903.
165. L. Mahawar et al., "Silicon nanoparticles: Comprehensive review on biogenic synthesis and applications in agriculture," Environ. Res., 2023, doi: 10.1016/j.envres.2023.116292.
166. X. Chen et al., "Influence of Elasticity of Hydrogel Nanoparticles on Their Tumor Delivery," Adv. Sci., 2022, doi: 10.1002/advs.202202644.
167. F. B. Ilhami, E. Erman, A. Rahmawati, Y. S. Birhan, Fitriana, and A. H. Tiwikrama, "Self-assembled supramolecular nanoparticle by host-guest interaction for thermo-controlled released of magnolol in cancer chemotherapy," J. Drug Deliv. Sci. Technol., 2023, doi: 10.1016/j.jddst.2023.105078.
168. M. G. Giordano, G. Seganti, M. Bartoli, and A. Tagliaferro, "An Overview on Carbon Quantum Dots Optical and Chemical Features," 2023. doi: 10.3390/molecules28062772.
169. S. Soni et al., "Herbal nanogels: Revolutionizing skin cancer therapy through nanotechnology and natural remedies," Eur. J. Med. Chem. Reports, 2024, doi: 10.1016/j.ejmcr.2023.100126.
170. H. Nsairat, D. Khater, U. Sayed, F. Odeh, A. Al Bawab, and W. Alshaer, "Liposomes: structure, composition, types, and clinical applications," 2022. doi: 10.1016/j.heliyon.2022.e09394.
171. W. C. Luo and X. Lu, "Solid Lipid Nanoparticles for Drug Delivery," Methods Mol. Biol., 2023, doi: 10.1007/978-1-0716-2954-3_12.
172. M. Elmowafy et al., "Polymeric Nanoparticles for Delivery of Natural Bioactive Agents: Recent Advances and Challenges," 2023. doi: 10.3390/polym15051123.
173. D. Zhang, X. L. Ma, Y. Gu, H. Huang, and G. W. Zhang, "Green Synthesis of Metallic Nanoparticles and Their Potential Applications to Treat Cancer," 2020. doi: 10.3389/fchem.2020.00799.
174. E. B. Souto, A. Cano, C. Martins-Gomes, T. E. Coutinho, A. Zielińska, and A. M. Silva, "Microemulsions and Nanoemulsions in Skin Drug Delivery," 2022. doi: 10.3390/bioengineering9040158.
175. S. A. Alkahtani, A. M. Mahmoud, Y. S. Alqahtani, A. M. B. H. Ali, and M. M. El-Wekil, "Selective detection of rutin at novel pyridinic-nitrogen-rich carbon dots derived from chicken feet biowaste: The role of bovine serum albumin during the assay," Spectrochim. Acta - Part A Mol. Biomol. Spectrosc., 2023, doi: 10.1016/j.saa.2023.123252.

176. D. Liu, Y. Zhao, J. Ji, X. Liu, S. Feng, and X. Chen, "Design of fluorescence system based on rutin functionalized gold nanoparticles: Sensitive detection of etimicin via a smartphone in the food and human samples," Arab. J. Chem., 2022, doi: 10.1016/j.arabjc.2022.104325.
177. Z. Nouri, S. Fakhri, K. Nouri, C. E. Wallace, M. H. Farzaei, and A. Bishayee, "Targeting multiple signaling pathways in cancer: The rutin therapeutic approach," 2020. doi: 10.3390/cancers12082276.
178. H. Qanash et al., "Phytochemical Characterization and Efficacy of Artemisia judaica Extract Loaded Chitosan Nanoparticles as Inhibitors of Cancer Proliferation and Microbial Growth," Polymers (Basel)., 2023, doi: 10.3390/polym15020391.
179. A. O. Falade et al., "Aqueous Extracts of Bay Leaf (Laurus nobilis) and Rosemary (Rosmarinus officinalis) Inhibit Iron-Induced Lipid Peroxidation and Key-Enzymes Implicated in Alzheimer's Disease in Rat Brain-in Vitro," Am. J. Biochem. Biotechnol., 2022, doi: 10.3844/ajbbsp.2022.9.22.
180. M. M. Kher, M. S. Shekhawat, M. Nataraj, and J. A. Teixeira da Silva, "Indian sarsaparilla, Hemidesmus indicus (L.) R. Br. ex Schult: tissue culture studies," 2020. doi: 10.1007/s00253-020-10714-9.