

# Cinnamon-Derived Bioactive Compounds as Emerging Anti-Acne Therapeutics: Mechanistic Insights, Pharmacological Evidence and Formulation Perspective

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## ABSTRACT

Acne vulgaris is a chronic inflammatory skin disorder characterized by multifactorial pathogenesis involving microbial colonization, excessive sebum production, follicular hyperkeratinisation, and inflammatory responses. Conventional therapies, including antibiotics, retinoids, and benzoyl peroxide, are often associated with adverse effects, antimicrobial resistance, and poor patient compliance, necessitating the exploration of safer and more effective alternatives. In this context, cinnamon-derived bioactive compounds have emerged as promising natural therapeutic agents due to their potent antimicrobial, anti-inflammatory, antioxidant, and wound-healing properties. Key constituents such as cinnamaldehyde, eugenol, and cinnamic acid exhibit significant inhibitory effects against acne-causing microorganisms, particularly *Cutibacterium acnes*, while also modulating inflammatory pathways such as NF- $\kappa$ B and MAPK signalling. Pharmacological evidence from *in vitro* and *in vivo* studies supports their efficacy in reducing bacterial load, inflammation, oxidative stress, and promoting skin repair. Furthermore, advances in formulation science, including nanoemulsions, liposomes, solid lipid nanoparticles, and hydrogels, have enhanced the stability, bioavailability, and dermal delivery of these bioactives. This review comprehensively discusses the mechanistic insights, pharmacological evidence, and formulation strategies associated with cinnamon-derived compounds, highlighting their potential as emerging anti-acne therapeutics and emphasizing the need for further clinical validation.

**Keywords:** Cinnamon; Cinnamaldehyde; Acne vulgaris; *Cutibacterium acnes*; Anti-inflammatory; Antioxidant; Nanoformulations; Herbal therapeutics; Skin delivery; Cosmeceuticals

## I. INTRODUCTION

Cinnamomum comes from the Greek word 'kinnamomon,' which means 'spice' and 'sweet

wood'. The bark from different cinnamon species is one of the most important and widely used spices worldwide, not only in cooking but also in traditional and modern medicine. In total, around 250 species of the *Cinnamomum* genus have been identified, with trees found in many different regions. Cinnamon is mainly used in the fragrance and aroma industries because of its scent. This scent can be added to many food items, perfumes, and medicinal products. The key compounds in cinnamon are cinnamaldehyde and trans-cinnamaldehyde (Cin), which are present in its essential oil. These compounds contribute to its scent and to the many health benefits linked to cinnamon (Huang *et al.*, 2016). Cinnamon has strong aromatic qualities and is used in both food and pharmaceutical industries. Its leaves and bark help with digestion, clean the blood, act as astringents, provide warmth, and work as antiseptics. They also have antibacterial, antifungal, and antiviral properties, as well as the ability to lower cholesterol and blood sugar levels. Camphor is an important chemical taken from *C. camphora*, used in medicines, especially in liniments and insecticides (Malabadiet *al.*, 2021). Its bark contains procyanidins and catechins, which are not only popular as spices but are also useful in managing type 2 diabetes and insulin resistance. This genus includes four main economically important cinnamon species: *Cinnamomum verum* (known as 'true cinnamon,' Sri Lankan, or *Ceylon cinnamon*), *Cinnamomum cassia* (called Chinese cinnamon), *Cinnamomum burmannii* (known as Java or Indonesian cinnamon), and *Cinnamomum loureiroi* (often referred to as Vietnamese or Saigon cinnamon) (Suriyagoda *et al.*, 2021).

*Cinnamon* is the fragrant bark and essential oils from trees in the genus *Cinnamomum*, mainly *C. verum* (commonly known as true or *Ceylon cinnamon*) and *C. cassia* (Cassia). People use these varieties worldwide as a spice in cooking and

as traditional medicine in Asia and beyond. The differences in their trade and cultivars, such as bark thickness and coumarin levels, are significant for both flavor and safety. Current research in botany and phytochemistry keeps redefining species classifications, harvesting methods, and compositional differences. These factors affect both culinary value and biological activity (Weisanyet *al.*, 2023). The plant's bioactivity results from a complex mix of volatile oils, particularly trans-cinnamaldehyde, tannins, polyphenols, and other phenylpropanoids. These components contribute to many of cinnamon's sensory qualities and its noted biological effects. Recent reviews in phytochemistry show that extraction method, plant part (bark versus leaf), and species significantly affect the amounts of cinnamaldehyde, eugenol, and coumarin. These variations influence antimicrobial effectiveness, antioxidant abilities, and safety profiles (Haldaret *al.*, 2022). In the last five years, targeted studies have reinforced evidence for various pharmacological actions. These include antimicrobial and antibiofilm properties, which are important for food safety and topical uses, as well as anti-inflammatory and antioxidant functions. Some clinical trials have shown slight improvements in glycemic and lipid markers. Research is exploring nano and delivery systems to address issues of volatility and solubility, which will help better formulate cinnamon components for medical or preservative uses. Recent studies have described mechanisms such as membrane disruption, enzyme modulation and effects on the NF- $\kappa$ B/inflammatory pathway. They suggest promising applications while emphasizing the need for higher-quality clinical trials (Luo and Song, 2021). Safety and regulatory concerns are vital. While normal dietary amounts of cinnamon are generally safe, high-dose supplements, particularly from Cassia cinnamon, raise concerns due to coumarin. This compound poses a risk of liver toxicity and may interact with drugs by modifying metabolic enzymes (Yun *et al.*, 2018).

## II. Acne

Acne is a common dermatological disease that mainly affects adolescents. It can lead to both physical and psychological effects, resulting in depression, poor self-esteem, and suicidal tendencies. Acne vulgaris is diagnosed by the presence of various clinical manifestations such as closed and open comedones, papules, pustules, cysts, and nodules (Kelly *et al.*, 2021). The underlying pathogenesis of these lesions is

multifactorial and includes high sebum secretion, hyperkeratinization, hormonal changes, and bacterial infection. *Propionibacterium acnes* play a significant role in the pathogenesis of acne. This bacterium can activate certain inflammatory mediators and metabolize sebaceous triglycerides into fatty acids, which induce the attraction of white blood cells to the plugged follicle, leading to skin inflammation (Zoubouliset *al.*, 2022). When the wall of the hair follicle is broken down, sebum, dead cells, and bacteria are secreted leading to a spectrum of acne severity. Current treatments of acne include topical therapies (comedolytic agents, antibiotics, and anti-inflammatory drugs) and systemic therapies (antibiotics, zinc, and hormones). However, these drugs cause various potential side effects, and long-term treatment with antibiotics may lead to the antibiotic resistance among acne-causing bacteria (Mohsin *et al.*, 2022).

Currently, many drug delivery systems are being developed for the treatment of acne. The novel carrier systems for acne application and treatment include liposome, niosome, microsphere, microemulsion, nanoemulsion, microsphere, and solid lipid nanoparticle. In this research cinnamon bark oil as an active agent was developed to nanogel dosage form. Nanogel can be formed by adding a gelling agent to a nanoemulsion system. Nanoemulsions are stable thermodynamically systems, either oil-in-water (O/W) or water-in-oil (W/O) emulsions that are nano-sized, and have droplet diameters around 10-200 nm (Safaya and Rotliwala 2020). Nanoemulsion is a dispersion system, which is two liquids that are not miscible and combined with the help of an emulsifying agent such as surfactants and cosurfactants. The advantages of using nanoemulsion for acne treatment are that it is an appropriate carrier for transporting lipophilic compounds into the skin and is considered ideal for acne. Nanoemulsion increases the active component's penetration inside the pilosebaceous unit since it has very small-sized droplets. Surfactant and co-surfactant in nanoemulsion formulation can act as penetration and occlusivity enhancer that improves skin penetration. Gelling agents can be added to the nanoemulsion system to form a nanoemulsion gel (nanogel). The addition of a gelling agent can increase the viscosity and adhesion of the nanoemulsion system, thus extending the contact time, in topical application (Priani *et al.*, 2022).

### III. Mechanistic Insights of Cinnamon-Derived Bioactive Compounds in Acne Management

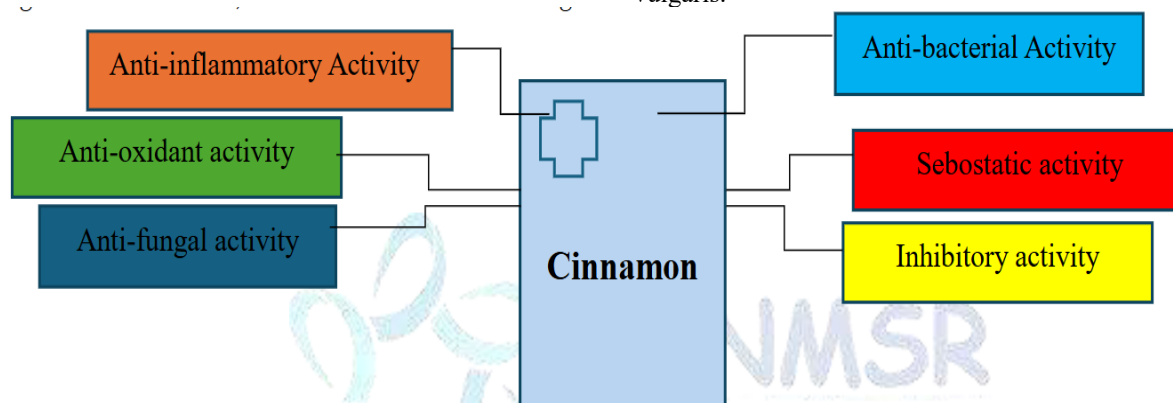


Figure 1: Mechanistic Insights of Cinnamon-Derived Bioactive Compounds

#### 3.1 Anti-inflammatory activity

The cinnamon gel twice a day for eight weeks dramatically decreased the number of total lesions (~47%), inflammatory lesions (~42%), erythema, and sebum content in individuals with mild to moderate facial acne. These are clinical correlates of reduced inflammation. Human monocytes (THP-1) treated with LPS, cinnamon extract, or isolated chemicals (trans-cinnamaldehyde, p-cymene) decreased IL-8 secretion, Akt phosphorylation, and I $\kappa$ B $\alpha$ , these pathways are comparable to those that C. acnes activate in acne. Pagliari, S., et al. stated that cinnamon bark extract continued to have anti-inflammatory properties in vitro after simulating digestion, lowering oxidative stress indicators or inflammatory markers (Ghovvatiet al., 2019). This implies possible topical or systemic advantages. According to research, cinnamon bark oil in the form of a nanoemulgel shows good anti-acne activity (antibacterial against P. acnes). Cinnamon essential oil nanogels dramatically decreased inflammation in animal models of inflammation (paw edema). Davoudi, F. proposed that cinnamon species improve antioxidant enzyme activities, inhibit NF- $\kappa$ B and MAPKs, and decrease TNF- $\alpha$ , IL-1 $\beta$ , and IL-6. Vallion et al., found that when cells are challenged with a TLR2/TLR-agonist (zymosan), cinnamaldehyde causes the transcription factor Nrf2 to accumulate at a lower concentration (100 $\mu$ M). This is linked to the suppression of pro-inflammatory cytokine mRNAs (such as IL-1 $\beta$  and TNF- $\alpha$ ) and a decrease in the pro-inflammatory response. However, at a greater dose (250  $\mu$ M), CinA had a pro-inflammatory effect

Cinnamon-derived phytoconstituents exert anti-acne effects through multi-targeted mechanisms, addressing all major pathogenic factors of acne vulgaris.

via increasing the levels of those cytokines rather than inducing Nrf2. The study also demonstrated that the lower dose's anti-inflammatory effects (i.e., increased cytokine release) were lost in keratinocytes with Nrf2 knockdown. Thus, Nrf2 appears to be crucial in changing the equilibrium (Panieriet al., 2023). This is significant because acne lesions are associated with keratinocyte inflammation, which results in the production of IL-1 $\beta$ , IL-8, and other chemicals. This suggests that cinnamaldehyde has a dose-dependent potential; at the right dosage, it may help reduce cytokines related to acne via Nrf2, but a high dose may make the condition worse. The study discovered that via blocking NF- $\kappa$ B and JNK signaling, cinnamon aldehyde inhibited keratinocyte growth and decreased the expression of important pro-inflammatory mediators. Additionally, it improved psoriasis-like lesions in mice, proving it's in vivo applicability. These findings support the idea that cinnamon aldehyde has anti-inflammatory effects in skin via signaling suppression, which may be applied to acne, even if psoriasis and acne differ (e.g., participation of P. acnes, sebum, etc.) (Nabavizadehet al., 2025).

#### 3.2 Anti-bacterial activity

The oil had a strong anti-C. acnes action. For P. acnes, Ameliana, L. & Rosyidi, V.A. discovered a formula (F3) with excellent antibacterial activity and good physical qualities. The nanoemulgel enhances transport, possibly by boosting interaction with bacterial cells and improving stability. Different doses of cinnamon

oil demonstrated inhibitory zones against MRSA and *S. aureus*; membrane damage is one of the causes. Cinnamon oil had a broad inhibition zone (~36.75 mm) against *P. acnes*; MIC was ~5 mg/mL. The concealer formulation with 0.5% cinnamon oil retained antibacterial action (Mulyaningsihet *et al.*, 2023). According to Wijayadi, cinnamon essential oil has antibacterial properties that can combat acne germs. According to the study, the main bioactive component is trans-cinnamaldehyde. It disrupts amino acid transport and energy balance in bacteria by covalently altering their proteins (such as the ATP-binding protein, ABC transporter, and NADH-quinone oxidoreductase). In addition to membrane damage, this provides a more profound understanding of the mechanisms influencing bacterial metabolism (Venkatakrishnan, 2016).

Using disc diffusion, the extract's inhibition zone against *P. acnes* was approximately 17.2 mm, whereas it was approximately 16.8 mm for *S. epidermidis*. The action of honey was comparable. According to study, the combination of cinnamon extract and honey had an additive effect (FICI = 0.625), which suggests that a combined treatment may permit lower doses of both. Cinnamaldehyde, eucalyptol, cinnamonyl acetate, and  $\alpha$ -limonene were the primary constituents in *C. burmannii* oil, according to the GC-MS study, whereas geraniol, citronellal, and citral were detected in *C. nardus* oil. The results of the Checkerboard assay indicated that there was no significant synergy or antagonism between the two oils and those microorganisms. Therefore, depending on the species and dosage, combination may not always increase effect (Juliantiet *et al.*, 2017).

### 3.3 Anti-oxidant activity

In cell models, the digested extract decreased indicators of oxidative stress and retained significant antioxidant ability (such as radical scavenging and reducing power). This implies that the antioxidants in cinnamon may have systemic effects and survive digestion. They observe a significant drop in red fluorescence spots in addition to a decrease in lesion counts, which is associated with oxidative activity and porphyrin synthesis by *C. acnes*. Decreased erythema and improved skin biophysical parameters also suggested less oxidative/inflammatory stress. Cinnamon dramatically reduced malondialdehyde (MDA), an indication of oxidative stress, and raised serum total antioxidant capacity. Acne is widespread in PCOS and is linked

to increased systemic oxidative stress, even though PCOS is not the same as acne (Zeber-Lubecka *et al.*, 2023). Cinnamaldehyde decreased the production of reactive oxygen species (ROS), stimulated the antioxidative enzyme Hmox1, decreased the buildup of malondialdehyde, and stopped the breakdown of collagen. While photoaging is not acne, oxidative stress and inflammation are similar mechanisms. These tests revealed that cinnamon essential oil had extremely high antioxidant activity. For instance, cinnamon EO was one of the best in the DPPH assay, the FOE (fish oil emulsion), and the RBC systems. This implies that lipid peroxidation and oxidative stress in skin and lipids may be lessened by cinnamon essential oil. Although the main goals were antibacterial/delivery rather than direct ROS or antioxidant assays, they do note that cinnamon oil contains cinnamaldehyde, which is known to have antioxidant action. This suggests that it may be an antioxidant (Zainebet *et al.*, 2022).

### 3.4 Sebum Regulation

Twenty patients with mild-to-moderate facial acne utilized a topical cinnamon gel twice a day for eight weeks. This study used a Sebumeter to evaluate sebum content, among other things. By week 8, the sebum content had significantly decreased to  $31.05 \pm 36.15$  units (baseline vs. week 8;  $p = 0.001$ ). Alongside this decline, there were improvements in other skin biophysical parameters (such as pH and erythema) and decreases in the numbers of total, inflammatory, and non-inflammatory acne lesions ( $\approx 47-48\%$ ). Although the study claimed that excessive sebum production is frequently the cause of acne, it did not provide direct measures of sebum content or excretion after using the cinnamon formulation (Hong *et al.*, 2025).

## IV. Mechanism of action

*C. acnes* are inhibited in vitro by cinnamon essential oil and cinnamon extracts. According to recent proteomics research, cinnamaldehyde covalently modifies bacterial proteins, interfering with bacterial transporters and metabolism. Cinnamon acnes contribute to inflammation in the pilosebaceous unit; reducing bacterial load reduces a key inflammatory stimulus. Cinnamaldehyde and a number of treatments containing cinnamon have been shown to interfere with the production of biofilms or lower their viability. Disrupting biofilms reduces chronic inflammation and makes bacteria more susceptible

to antibiotics. In mammalian cells, cinnamon's components inhibit pro-inflammatory signaling. Laboratory studies have demonstrated mechanisms such as decreased expression of adhesion molecules and chemokines, suppression of NF- $\kappa$ B signaling, and down regulation of inflammatory mediators (e.g., TNF- $\alpha$ , IL-1 $\beta$ , and IL-6) (Didehdaret *et al.*, 2022). These measures lessen the follicle's local inflammation and the recruitment of neutrophils and macrophages. *In vitro*, cinnamon extracts increase antioxidant responses and scavenge reactive oxygen species (ROS). Cinnamon may lessen tissue damage and inflammatory amplification that exacerbate lesion formation by reducing oxidative stress surrounding the pilosebaceous unit. In individuals with mild-to-moderate acne, topical cinnamon gel was found to lower erythema, sebum levels, and lesion counts in small clinical pilot investigations. Although the exact molecular mechanism for sebum reduction is not fully understood, this shows cinnamon preparations may also influence sebum. According to study these clinical findings are tentative and require larger trials. When synthesized in liposomes cinnamon essential oil or cinnamaldehyde frequently exhibits synergy with other antimicrobials. Because essential oils can be irritating at greater quantities, formulation is crucial for both efficacy and tolerability (Ellboudy *et al.*, 2023).

## V. *In Vitro* Pharmacological Studies

### 5.1 Anti-Biofilm Activity

Biofilm formation plays a crucial role in enhancing bacterial resistance and persistence within acne lesions, thereby contributing to chronic and treatment-resistant conditions. Cinnamon-derived compounds, particularly cinnamaldehyde, have shown remarkable anti-biofilm activity against *Cutibacterium acnes* and *Staphylococcus epidermidis*. Studies indicate that cinnamaldehyde can inhibit biofilm formation by approximately 70–90%, significantly reducing bacterial adhesion and colonization. This effect is primarily mediated through interference with quorum sensing mechanisms, which regulate bacterial communication and coordination, as well as inhibition of extracellular polymeric substance (EPS) synthesis, a key structural component of biofilms. The ability of cinnamon bioactives to disrupt biofilm formation is especially valuable in overcoming antimicrobial resistance and improving therapeutic outcomes in chronic acne (Kiymaci and Kaskatepe 2022).

### 5.2 Cytotoxicity and Safety (Cell Viability Studies)

Safety evaluation of cinnamon-derived bioactive compounds has been conducted using *in vitro* cytotoxicity assays on keratinocyte and fibroblast cell lines. The results indicate that cinnamon extracts and their active constituents are generally non-toxic at therapeutic concentrations, demonstrating good biocompatibility for topical application. However, dose-dependent cytotoxic effects have been observed at higher concentrations, particularly above 100  $\mu$ g/mL, suggesting the importance of optimizing dosage in formulation development. Overall, these findings support the safe use of cinnamon bioactives in dermatological applications, provided that appropriate concentrations and delivery systems are employed to minimize potential adverse effects (Guo *et al.*, 2024).

## VI. *In Vivo* Pharmacological Studies

*In vivo* studies using animal models provide critical insights into the systemic and topical efficacy of cinnamon-derived bioactive compounds in acne management. These models help bridge the gap between *in vitro* findings and clinical applications by evaluating biological responses in complex living systems. Various experimental studies have demonstrated that cinnamon bioactives possess significant anti-inflammatory, antimicrobial, antioxidant, and wound-healing properties, all of which are highly relevant to acne therapy (Varghese *et al.*, 2026).

### 6.1 Antimicrobial Efficacy in Skin Infection Models

The antimicrobial activity of cinnamon bioactives has also been validated through *in vivo* skin infection models. These studies demonstrate that treatment with cinnamon extracts or essential oil leads to a significant reduction in bacterial colony counts at the site of infection, indicating effective bacterial clearance. Additionally, cinnamon-treated groups exhibit faster resolution of infection compared to untreated controls. In some cases, the antimicrobial efficacy of cinnamon oil has been found to be comparable to that of standard antibiotics, suggesting its potential as a natural alternative or adjunct therapy. This is particularly important in the context of increasing antibiotic resistance among acne-causing microorganisms (Didehdaret *et al.*, 2022).

## 6.2 Antioxidant and Skin Protective Effects

Cinnamon-derived bioactives have demonstrated notable antioxidant and skin-protective effects in *in vivo* models. Treatment with cinnamon extracts has been shown to enhance the activity of endogenous antioxidant enzymes, including superoxide dismutase (SOD) and catalase (CAT), which play a vital role in neutralizing reactive oxygen species. Concurrently, a significant reduction in oxidative stress markers, particularly malondialdehyde (MDA), has been observed. These effects indicate a protective role against oxidative damage in skin tissues, including sebaceous glands, thereby preventing lipid peroxidation and inflammation associated with acne pathogenesis (Banaszak *et al.*, 2024).

## 6.3 Wound Healing and Anti-Scar Activity

In addition to its antimicrobial and anti-inflammatory effects, cinnamon bioactives contribute significantly to wound healing and skin repair processes. *In vivo* studies have demonstrated that cinnamon treatment accelerates wound contraction, promotes collagen synthesis, and enhances epithelial regeneration. These effects facilitate faster healing of damaged skin and reduce the risk of scar formation. The increased collagen deposition and improved tissue remodeling associated with cinnamon bioactives are particularly beneficial in minimizing post-acne scarring and hyperpigmentation, thereby improving overall skin appearance and recovery (SeyedAhmadi *et al.*, 2019).

## VII. *Ex Vivo* and Skin Permeation Studies

*Ex vivo* studies employing excised human or animal skin models play a crucial role in understanding the permeation behavior and dermal delivery of cinnamon-derived bioactive compounds. These models closely mimic *in vivo* skin conditions and provide valuable insights into drug penetration, retention, and distribution across different skin layers. Studies have demonstrated that cinnamon essential oil exhibits efficient permeation through the stratum corneum, primarily due to its lipophilic nature, which facilitates diffusion across the skin barrier (Caliskan and Karakus 2020). Furthermore, the development of advanced nanoformulations, such as nanoemulsions, liposomes, and lipid-based carriers, has been shown to significantly enhance skin penetration compared to crude extracts by improving solubility, stability, and interaction with skin lipids. In addition, controlled release delivery systems contribute to prolonged retention of

bioactive compounds within the epidermal and dermal layers, thereby enhancing therapeutic efficacy and reducing the frequency of application. Collectively, these findings underscore the importance of formulation strategies in optimizing the topical delivery of cinnamon bioactives and highlight their potential in the development of effective anti-acne therapies (Mandal *et al.*, 2025).

## VIII. Formulation Perspectives of Cinnamon-Based Anti-Acne Products

The effectiveness of cinnamon-derived bioactive compounds in acne management is strongly influenced by the choice of delivery system and formulation strategy. Proper formulation not only ensures stability and optimal skin penetration but also enhances patient compliance and therapeutic outcomes. Among various approaches, conventional topical formulations remain the most widely used due to their simplicity, cost-effectiveness, and ease of application (Mishra, 2024).

### 8.1 Conventional Topical Formulations

Conventional dosage forms such as gels, creams, lotions, and cleansers serve as the primary vehicles for delivering cinnamon bioactives to the skin. These formulations are designed to provide localized action, minimize systemic absorption, and improve patient acceptability.

#### • Gels

Gels are among the most preferred dosage forms for anti-acne therapy, particularly for individuals with oily and acne-prone skin. They are typically aqueous or hydroalcoholic systems that provide a non-greasy, lightweight, and cooling effect upon application. Cinnamon bioactives incorporated into gel formulations exhibit enhanced drug release due to the high water content and porous structure of the gel matrix. This facilitates efficient diffusion of active compounds through the skin, leading to improved therapeutic efficacy (Kaur *et al.*, 2020).

Additionally, gels allow uniform distribution of the active ingredient over the affected area and are easily washable, making them suitable for frequent use. The inclusion of suitable gelling agents such as carbopol or hydroxypropyl methylcellulose (HPMC) can further optimize viscosity, spreadability, and stability. Importantly, gel formulations reduce the risk of pore blockage, which is a critical factor in acne management. Their compatibility with alcohol-based systems also aids in solubilizing lipophilic compounds like cinnamaldehyde, thereby enhancing bioavailability (Rahmani and Zulkarnain 2023).

### • Creams and Lotions

Creams and lotions are semi-solid and liquid emulsions, respectively, that provide both therapeutic and cosmetic benefits. These formulations are particularly useful when acne is associated with dryness, irritation, or compromised skin barrier function. Creams, being thicker emulsions, offer better occlusion and prolonged contact time, which can enhance the absorption of cinnamon bioactives into deeper skin layers. Lotions, on the other hand, are lighter and more fluid, making them suitable for application over larger surface areas (Tayyib, 2025).

The presence of emollients and humectants in these formulations helps maintain skin hydration, reducing irritation that may arise from active compounds such as cinnamaldehyde. Furthermore, creams and lotions are often used in combination therapies, where cinnamon bioactives are incorporated alongside other anti-acne agents such as salicylic acid, niacinamide, or herbal extracts to achieve synergistic effects. These formulations also improve patient compliance due to their pleasant texture, ease of application, and enhanced cosmetic appeal (Jayronia *et al.*, 2024).

### • Face Washes and Cleansers

Face washes and cleansers containing cinnamon bioactives are widely used as part of daily skincare regimens for acne management. These formulations are designed to provide short-contact antimicrobial action, helping to reduce the microbial load on the skin surface without prolonged exposure. Cinnamon-based cleansers effectively remove excess sebum, dirt, and impurities, which are key contributors to acne development (Varghese *et al.*, 2026).

The inclusion of mild surfactants ensures effective cleansing while minimizing skin irritation. Cinnamon bioactives in these formulations exert rapid antimicrobial and antioxidant effects during the brief contact period, helping to control acne-causing bacteria and reduce oxidative stress. Additionally, regular use of such cleansers can help maintain skin hygiene, prevent pore blockage, and reduce the frequency of acne flare-ups. Formulation considerations include maintaining an appropriate pH (typically 5.5–6.5) to preserve the skin barrier and incorporating soothing agents such as aloe vera or glycerin to counteract potential irritation (Mohiuddin, 2019).

### 8.2 Advanced Drug Delivery Systems

Advanced drug delivery systems have emerged as highly effective strategies to overcome the

limitations associated with conventional formulations of cinnamon-derived bioactive compounds, such as poor aqueous solubility, volatility, instability, and potential skin irritation. These modern systems are designed to enhance the therapeutic performance of bioactives like cinnamaldehyde by improving their solubility, stability, penetration, and controlled release, thereby maximizing efficacy while minimizing adverse effects (Touatiet *et al.*, 2025).

### • Nanoemulsions

Nanoemulsions are thermodynamically or kinetically stable colloidal dispersions consisting of oil and water phases stabilized by surfactants, with droplet sizes typically in the nanometer range (20–200 nm). These systems are particularly suitable for delivering lipophilic compounds such as cinnamaldehyde. By reducing droplet size, nanoemulsions significantly improve the solubility and dispersion of hydrophobic bioactives, thereby enhancing their bioavailability (Jafari and McClement 2018).

The small droplet size also facilitates better interaction with the stratum corneum, leading to improved skin penetration and deeper permeation of active compounds. Additionally, nanoemulsions provide a large surface area for drug release, enabling controlled and sustained delivery. Their transparent or translucent appearance, low viscosity, and ease of application further contribute to patient acceptability. Moreover, nanoemulsions can be tailored by selecting appropriate oils, surfactants, and co-surfactants to optimize stability and therapeutic performance (Rehman *et al.*, 2017).

### • Liposomes and Phytosomes

Liposomes are spherical vesicular systems composed of phospholipid bilayers capable of encapsulating both hydrophilic and lipophilic compounds. Phytosomes, on the other hand, are complexes formed between plant-derived bioactives and phospholipids, enhancing their bioavailability and stability. These systems are highly advantageous for delivering cinnamon bioactives in topical applications (Yadav, 2017).

Liposomes enhance the stability of sensitive compounds like cinnamaldehyde by protecting them from environmental degradation such as oxidation and volatilization. Their structural similarity to biological membranes allows them to fuse with skin lipids, facilitating targeted delivery to deeper layers of the skin. Phytosomes further improve the absorption of bioactives by increasing their lipid compatibility, thereby enhancing permeation through the skin barrier. An additional benefit of

these vesicular systems is their ability to reduce irritation potential. By encapsulating the active compounds, direct contact with the skin is minimized, leading to a more controlled release and improved tolerability, especially for sensitive skin(Vaishnavi *et al.*, 2021).

- **Solid Lipid Nanoparticles (SLNs) and Nanostructured Lipid Carriers (NLCs)**

Solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs) represent advanced lipid-based delivery systems that have gained considerable attention in dermatological applications. SLNs are composed of solid lipids, while NLCs are formulated using a combination of solid and liquid lipids, which improves drug loading capacity and reduces crystallinity issues(Shirodkar *et al.*, 2019). These systems provide sustained and controlled release of cinnamon bioactives, ensuring prolonged therapeutic action and reducing the need for frequent application. The lipid matrix protects bioactive compounds from chemical degradation, such as oxidation and photodegradation, thereby enhancing formulation stability. Furthermore, SLNs and NLCs improve dermal retention by forming a lipid film on the skin surface, which facilitates closer contact with the stratum corneum and enhances penetration. Their occlusive properties also help in maintaining skin hydration, which can further support the healing process in acne-affected skin. Additionally, these carriers minimize systemic absorption and reduce irritation, making them highly suitable for long-term topical use(Souto *et al.*, 2022).

- **Hydrogels and Nanogels**

Hydrogels and nanogels are three-dimensional, hydrophilic polymeric networks capable of retaining large amounts of water. These systems are particularly advantageous for topical delivery due to their soothing, cooling, and non-irritating properties. When loaded with cinnamon bioactives, hydrogels provide a uniform and controlled release of active compounds over an extended period(Delgado-Pujol *et al.*, 2025).

The high water content of hydrogels enhances skin hydration and creates a favorable environment for wound healing and tissue repair. Nanogels, which are nanoscale hydrogel particles, offer additional benefits such as improved penetration, higher surface area, and enhanced interaction with skin tissues. These systems increase the residence time of bioactives on the skin, thereby improving therapeutic efficacy. Furthermore, hydrogels and nanogels are aesthetically appealing, non-greasy, and easy to apply and remove, contributing to better patient compliance. Their ability to incorporate both

hydrophilic and hydrophobic components makes them versatile carriers for combination therapies(Sivaram *et al.*, 2015).

## IX. Conclusion

Cinnamon-derived bioactive compounds demonstrate multifunctional anti-acne activity through antimicrobial, anti-inflammatory, antioxidant, and skin-repair mechanisms. Pharmacological evidence supports their therapeutic potential, while modern formulation strategies significantly enhance their efficacy and safety. Despite promising outcomes, further clinical validation and formulation optimization are necessary for their successful translation into mainstream dermatological practice. Cinnamon generally has tremendous potential as a natural anti-acne agent due to its richness of bioactive compounds, such as cinnamonaldehyde, eugenol, coumarins, and other flavonoids. Together, these components reduce oxidative stress, inflammation, and excessive sebum production, three major factors in the development of acne; while also fighting acne-causing bacteria like *P. acnes*, *S. aureus*, *S. epidermidis*, and *S. pyogenes*. Cinnamon essential oil, gels, and other extracts have been shown in lab experiments to have antibacterial, antioxidant, and anti-inflammatory qualities. Although current research suggests that cinnamon may be a moderate and effective alternative to conventional acne medications, well-designed clinical trials are still needed to assess the safest dosages, the best formulations, and the long-term effects. In conclusion, cinnamon has a lot of potential in dermatology, particularly for managing acne, but more human-centered research is necessary before it can be widely advised in clinical practice.

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