

***Cinnamomum verum*: A Critical Review of Its Phytochemical Constituents and Therapeutic Applications.**

Parwan Ali Ujjan (Corresponding Author)

Department of Biochemistry, Shah Abdul Latif University Khairpur

Email: parwanaliujjan@gmail.com & Parwan.ali@salu.edu.pk

+92-304-3523778

Shakeel Ahmed Ibupoto

Date Palm Research Institute, Shah Abdul Latif University Khairpur

Abdul Wahab Lighari

Institute of Physiology, University of Sindh

Shumaila Aurangzaib

Department of Pharmacology, Federal Urdu University

Dua Khowaja

Institute of Physiology, University of Sindh

Dr. Shahnila

Gyne unit-1 SZWH Larkana, University SMBBMU Larkana

Shazia Parveen Solangi

Department of Biochemistry, Shah Abdul Latif University Khairpur

Maqbool Ahmed Soomro

Department of Biochemistry, Shah Abdul Latif University Khairpur

Author Details

Keywords: *Cinnamomum verum*; Ceylon Cinnamon; Phytochemicals; Phenylpropanoids; Flavonoids; Proanthocyanidins; Cinnamaldehyde; Eugenol; Antioxidant Activity; Anti-Inflammatory; Antimicrobial; Antidiabetic; Neuroprotection; Nf-Kb; Mapk; Pi3k/Akt; Nrf2 Signaling; Functional Foods; Nutraceuticals.

Received on 01 Sep 2025

Accepted on 25 Sep 2025

Published on 06 Oct 2025

Corresponding E-mail & Author*:

Parwan Ali Ujjan

Department of Biochemistry, Shah Abdul Latif University Khairpur

Email: parwanaliujjan@gmail.com

Parwan.ali@salu.edu.pk

Abstract

This review provides a critical analysis of the phytochemical composition and pharmacological efficacy of Ceylon cinnamon (*Cinnamomum verum* J. Presl), a culinary staple with extensive ethnomedicinal use. Recent investigations confirm that the spice's broad therapeutic spectrum is directly attributable to a diverse profile of secondary metabolites, predominantly comprising phenylpropanoids (e.g., cinnamaldehyde and eugenol), various flavonoids, proanthocyanidins, and terpenoids. The integrated pharmacological evidence supports the use of *C. verum* as a potent agent against several chronic human health challenges. Its documented effects include robust antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and neuroprotective activities. Mechanistically, these beneficial effects are achieved through the modulation of critical cellular signaling cascades. Bioactive constituents are shown to regulate pathways such as NF- κ B, MAPK, PI3K/Akt, and Nrf2, which govern inflammation and

oxidative stress responses. Furthermore, *C. verum* exhibits direct inhibitory effects on β -amyloid aggregation—a hallmark of neurodegenerative pathology—and on carbohydrate-digesting enzymes, which is relevant to postprandial glucose control. Significantly, the species is distinguished by its negligible coumarin content, contrasting sharply with common cassia varieties. This enhanced safety profile is a key

factor underscoring its suitability for long-term or chronic application. By synthesizing these phytochemical and mechanistic insights, this review validates *C. verum*'s potential as a highly effective functional food ingredient and a promising lead candidate for nutraceutical development aimed at mitigating metabolic disorders, infectious diseases, and neurodegeneration driven by oxidative stress.

Abbreviations:

DPPH – 2,2-diphenyl-1-picrylhydrazyl; NO – nitric oxide; ROS – reactive oxygen species; MIC – minimum inhibitory concentration; MLE – methanolic leaf extract; NF- κ B – Nuclear Factor-kappa B; MAPK – Mitogen-Activated Protein Kinase; COX – Cyclooxygenase; LOX – Lipoxygenase; Nrf2 – Nuclear Factor Erythroid 2-Related Factor 2; PI3K – Phosphoinositide 3-Kinase; Akt – Protein Kinase B; GLUT4 – Glucose Transporter Type 4; ACE2 – Angiotensin-Converting Enzyme 2; TMPRSS2 – Transmembrane Serine Protease 2; TNF- α – Tumor Necrosis Factor-alpha; IL-1 β – Interleukin-1 beta; IL-6 – Interleukin-6; HbA1c – Glycated Hemoglobin.

Introduction

Cinnamomum verum J. Presl, commonly known as Ceylon cinnamon or “true cinnamon,” is an evergreen tree belonging to the Lauraceae family. It has been revered for centuries in traditional medicine systems, particularly in Ayurveda, Unani, and Traditional Chinese Medicine, for its therapeutic and aromatic properties (Sharifi-Rad *et al.*, 2021; Ju *et al.*, 2023; Guo *et al.*, 2024). Various parts of the plant, including the bark, leaves, and roots, have been utilized to treat a wide range of ailments. In Ayurveda, *C. verum* has been employed to manage digestive disorders such as indigestion and diarrhea, respiratory conditions like cough and bronchitis, and inflammatory diseases (Kumari *et al.*, 2019; Sharma *et al.*, 2024). Its bark and essential oils have also been used to alleviate menstrual irregularities, improve circulation, and act as a general tonic (Sharifi-Rad *et al.*, 2021; Guo *et al.*, 2024).

The therapeutic potential of *C. verum* is attributed to its diverse phytochemical constituents, including cinnamaldehyde, eugenol, cinnamic acid, flavonoids, and phenolic compounds (Pagliari *et al.*, 2023; Guo *et al.*, 2024). These bioactive compounds exhibit a broad spectrum of pharmacological activities such as antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and anticancer effects (Ju *et al.*, 2023; Sharma *et al.*, 2024). Cinnamaldehyde, the major component of cinnamon bark oil, has been shown to modulate inflammatory pathways and inhibit microbial growth, while eugenol contributes to analgesic and antiseptic properties (Guo *et al.*, 2024). Recent studies have also highlighted its neuroprotective and cardioprotective roles, suggesting its potential in managing chronic diseases like diabetes, cardiovascular disorders, and neurodegenerative conditions (Ju *et al.*, 2023; Virutkar *et al.*, 2023).

The resurgence of interest in natural products for drug discovery is driven by limitations of synthetic drugs, including adverse effects, toxicity, and the emergence of drug resistance (Newman & Cragg, 2020; Guo *et al.*, 2024). Natural products, with their structural diversity and complex mechanisms of action, offer a rich source of novel therapeutic agents (Harvey, 2008; Ju *et al.*, 2023). Traditional medicine systems provide valuable insights into the efficacy and safety of these natural compounds, forming the basis for modern pharmacological investigations (Sharifi-Rad *et al.*, 2021; Sharma *et al.*, 2024). The increasing prevalence of chronic diseases and lifestyle disorders has further fueled the demand for plant-based remedies and functional foods, positioning *C. verum* as a promising candidate for nutraceutical and pharmaceutical applications (Pagliari *et al.*, 2023).

Advancements in analytical techniques such as high-performance liquid chromatography (HPLC), gas chromatography-mass spectrometry (GC-MS), and

nuclear magnetic resonance (NMR) spectroscopy have significantly enhanced the ability to identify and isolate bioactive compounds from *C. verum* (Guo *et al.*, 2024; Sharma *et al.*, 2024). These technological breakthroughs, combined with computational chemistry and molecular docking studies, have accelerated the drug discovery process by elucidating mechanisms of action and predicting pharmacokinetic properties (Ju *et al.*, 2023). Such integrative approaches have paved the way for the development of standardized cinnamon-based formulations with improved efficacy and safety profiles. In conclusion, the combination of historical knowledge, modern scientific validation, and technological advancements underscores the importance of *Cinnamomum verum* as a versatile medicinal plant. Its rich phytochemical profile and diverse pharmacological activities make it a valuable resource for developing innovative therapies to address unmet medical needs. However, further research is essential to establish clinical efficacy, optimize dosage, and ensure long-term safety (Sharifi-Rad *et al.*, 2021; Guo *et al.*, 2024). By bridging traditional wisdom with modern science, researchers can unlock the full therapeutic potential of *C. verum* and contribute to the advancement of natural product-based drug discovery.

Cinnamomum verum: A Botanical Overview

Taxonomy and Botanical Description

Cinnamomum verum J. Presl, commonly known as Ceylon cinnamon or “true cinnamon,” belongs to the family Lauraceae and the genus Cinnamomum. It is a small to medium-sized evergreen tree native to Sri Lanka and southern India, though it is now cultivated in several tropical regions worldwide, including Madagascar, Seychelles, and parts of Southeast Asia (Saha *et al.*, 2023). The species was historically referred to as *Cinnamomum zeylanicum* Blume, which remains a widely recognized synonym (Soumya & Krishnamohan, 2024).

Table 1:Taxonomic Classification of *Cinnamomum verum*

Category	Classification
Kingdom	Plantae
Clade	Angiosperms
Order	Laurales
Family	Lauraceae
Genus	Cinnamomum
Species	<i>Cinnamomum verum</i> J. Presl

Botanical Description

Cinnamomum verum is an aromatic evergreen tree that typically grows 8–15 meters in height in its natural habitat, though cultivated plants are often pruned to about 3 meters for easier harvesting. The trunk is stout, with a diameter of 30–60 cm, and covered by a thick, greyish-brown bark that is the primary source of the spice cinnamon. The leaves are simple, opposite, and leathery, measuring 5–18 cm long and 3–10 cm wide, with an ovate to elliptic shape. They exhibit three prominent longitudinal veins running from the base to the apex. Young leaves are reddish and later turn dark green on the upper surface with paler undersides (Prathibhani *et al.*, 2023). The flowers are small (about 3 mm in diameter), pale yellow to greenish, and arranged in axillary or terminal panicles. They emit a slightly unpleasant odor and bloom seasonally. The fruit is a fleshy, ovoid drupe, about 1–1.5 cm long, turning from green to purple or black when ripe, and contains a single seed (Ranasinghe *et al.*, 2023).

Table 2 Botanical Characteristics of *Cinnamomum verum*

Feature	Description
Plant Type	Aromatic evergreen tree

Height	8–15 m (wild); pruned to ~3 m in cultivation
Trunk	Stout, 30–60 cm diameter, greyish-brown bark
Leaves	Simple, opposite, leathery; 5–18 × 3–10 cm; ovate to elliptic; 3 prominent veins
Young Leaves	Reddish, turning dark green above and pale beneath
Flowers	Small (3 mm), pale yellow-green, in axillary or terminal panicles; seasonal bloom
Fruit	Fleshy ovoid drupe, 1–1.5 cm; green to purple/black when ripe; single seed

Habitat and Distribution

C. verum thrives in tropical climates with an annual rainfall of over 2,000 mm and prefers well-drained soils. It is primarily grown in Sri Lanka, which accounts for the majority of global production, but it is also cultivated in India, Madagascar, and other tropical regions (Andrade-Hoyos *et al.*, 2023).

Geographical Distribution and Ecological Significance

Cinnamomum verum J. Presl, commonly known as Ceylon cinnamon, is native to the wet evergreen forests of Sri Lanka and the Western Ghats of India, where it thrives in tropical climates with high humidity and well-drained soils (Ranasinghe *et al.*, 2023). Today, its cultivation has expanded to several tropical regions, including Madagascar, Seychelles, and parts of Southeast Asia, due to its economic and medicinal importance (Guo *et al.*, 2024). Sri Lanka remains the primary global producer, accounting for more than 80% of the world’s Ceylon cinnamon supply (Ranasinghe *et al.*, 2023).

Geographical Distribution:

C. verum grows optimally in regions with annual rainfall between 1,250–2,500 mm and temperatures ranging from 20°C to 30°C (Pagliari *et al.*, 2023). It prefers sandy loam soils rich in organic matter and is commonly cultivated in lowland tropical zones up to 1,000 meters above sea level (Guo *et al.*, 2024). While it is primarily grown in Sri Lanka, commercial plantations are also found in India (Kerala, Tamil Nadu), Madagascar, and the Caribbean islands, where similar agro-climatic conditions prevail (Ranasinghe *et al.*, 2023).

Table 3. Geographical Distribution of *Cinnamomum verum*

Parameter	Details
Native Range	Sri Lanka and Western Ghats of India
Current Cultivation	Sri Lanka, India (Kerala, Tamil Nadu), Madagascar, Seychelles, Caribbean, Southeast Asia
Optimal Rainfall	1,250–2,500 mm annually
Temperature Range	20°C–30°C
Soil Preference	Sandy loam, rich in organic matter, well-drained
Altitude	Up to 1,000 m above sea level

Ecological Significance:

Cinnamomum verum plays a vital role in tropical forest ecosystems as an evergreen species that contributes to soil stabilization, carbon sequestration, and biodiversity conservation (Guo *et al.*, 2024). Its dense canopy provides habitat for various insects and birds, while its flowers serve as a nectar source for pollinators, particularly bees

and flies (Pagliari *et al.*, 2023). Additionally, cinnamon plantations help prevent soil erosion in hilly regions and support agroforestry systems, promoting sustainable land use (Ranasinghe *et al.*, 2023). From an economic and ecological perspective, cinnamon cultivation offers environmentally friendly income opportunities for rural communities, reducing pressure on natural forests by providing an alternative to timber extraction (Guo *et al.*, 2024). Furthermore, the use of cinnamon-based agroforestry systems enhances soil fertility and water retention, contributing to climate resilience in tropical regions (Pagliari *et al.*, 2023).

Table 4.Ecological Significance of *Cinnamomum verum*

Aspect	Ecological Role
Soil Stabilization	Prevents erosion in hilly regions
Carbon Sequestration	Contributes to climate regulation
Biodiversity	Provides habitat for insects and birds
Pollination	Flowers serve as nectar source for bees and flies
Agroforestry Role	Enhances soil fertility, water retention, and sustainable land use
Economic Impact	Provides eco-friendly income, reduces pressure on natural forests

Traditional Uses of *Cinnamomum verum* in Various Cultures

Cinnamomum verum J. Presl, commonly known as Ceylon cinnamon, has been an integral part of traditional medicine, cultural practices, and religious rituals for centuries. Its applications span across medicinal, ornamental, and spiritual domains, reflecting its multifaceted significance in human societies.

Medicinal Uses

In traditional medicine systems such as Ayurveda, Unani, and Traditional Chinese Medicine, *C. verum* has been extensively used to treat a variety of ailments. In Ayurveda, it is classified as a warming spice and prescribed for digestive disorders (indigestion, diarrhea), respiratory conditions (cough, bronchitis), and circulatory issues (Sharifi-Rad *et al.*, 2021; Kumar *et al.*, 2019). Its bark and essential oils have been used as carminative, antiseptic, and anti-inflammatory agents, while decoctions were administered for menstrual irregularities and as a general tonic (Pathak & Sharma, 2021). In Chinese medicine, cinnamon bark (Rou Gui) is considered a yang tonic, used to warm the body, improve kidney function, and alleviate cold-related disorders (Sharifi-Rad *et al.*, 2021).

Modern pharmacological studies have validated many of these traditional claims, demonstrating that cinnamon possesses antioxidant, antimicrobial, antidiabetic, and anti-inflammatory properties, primarily due to its bioactive compounds such as cinnamaldehyde and eugenol (Kumar *et al.*, 2019; Pagliari *et al.*, 2023).

Ornamental Uses

Beyond its medicinal value, *C. verum* is cultivated as an ornamental plant in tropical gardens due to its evergreen foliage and aromatic bark. Its glossy green leaves and fragrant nature make it a popular choice for landscaping in regions where it thrives (Sharifi-Rad *et al.*, 2021). Additionally, cinnamon trees are often integrated into agroforestry systems, contributing to biodiversity and soil conservation while providing economic benefits to farmers (Ranasinghe *et al.*, 2023).

Religious and Cultural Significance

Cinnamomum verum holds a prominent place in religious rituals and cultural traditions across Asia and the Middle East. In Hindu rituals, cinnamon is used in incense and offerings for its pleasant aroma and symbolic association with purity and prosperity (Sharifi-Rad *et al.*, 2021). In ancient Egypt, cinnamon was employed in mummification and temple offerings, signifying its sacred status (Touwaide & Appetiti, 2024). Similarly, in Christian traditions, cinnamon was historically valued as a precious spice mentioned in biblical texts, symbolizing wealth and divine favor (Touwaide & Appetiti, 2024).

The widespread use of cinnamon in culinary practices also reflects its cultural importance. It is a key ingredient in traditional dishes, sweets, and beverages across South Asia, the Middle East, and Europe, often associated with festive occasions and hospitality (Pathak & Sharma, 2021).

Phytochemical Profile of *Cinnamomum verum*

A Comprehensive Review of the Major Phytochemical Classes Identified in the Plant

The phytochemistry of *Cinnamomum verum* is dominated by phenylpropanoids, particularly in its volatile fraction, along with polyphenols (including proanthocyanidins and flavonoids) and a diverse set of terpenoids. Minor or sporadic reports also indicate the presence of alkaloids, lignans, and coumarins, although coumarin levels in *C. verum* are significantly lower than in cassia, making it safer for long-term consumption (Singh *et al.*, 2020; Liu *et al.*, 2021; Rana & Sheu, 2023). These phytochemical classes collectively underpin the plant's antioxidant, anti-inflammatory, antimicrobial, and metabolic health benefits (Guo *et al.*, 2024).

Volatile (essential-oil) phenylpropanoids The essential oil fraction of *C. verum* bark is primarily composed of (E)-cinnamaldehyde, which often accounts for 70–90% of the oil, while the leaf oil is typically rich in eugenol (Farias *et al.*, 2020; Narayanankutty *et al.*, 2021). Chemotype studies reveal significant variability in oil composition across geographic regions, with some leaf oils dominated by linalool or benzyl-benzoate (Xavier *et al.*, 2022; Saha *et al.*, 2023). These variations influence both aroma and pharmacological activity.

Polyphenols (non-volatile) The non-volatile fraction of *C. verum* contains abundant proanthocyanidins (A-type and B-type), phenolic acids (such as cinnamic and gallic acids), and flavonoids (including kaempferol, quercetin, and rutin) (Liu *et al.*, 2021; Pagliari *et al.*, 2023). Advanced LC–MS and UPLC analyses have quantified procyanidin dimers and trimers, which are key contributors to antioxidant and anti-inflammatory properties.

Terpenoids. Beyond eugenol, *C. verum* essential oils contain monoterpenes (e.g., linalool, α -terpineol) and sesquiterpenes (e.g., β -caryophyllene), which contribute to antimicrobial and antioxidant activities (Farias *et al.*, 2020; Xavier *et al.*, 2022).

Alkaloids and lignans. While genus-level studies report alkaloids and lignans in *Cinnamomum* species, their presence in *C. verum* is minimal and requires further targeted research (Singh *et al.*, 2020).

Coumarins (safety context). Analytical studies confirm that *C. verum* contains negligible coumarin compared to cassia, reinforcing its safety for culinary and medicinal use (Liu *et al.*, 2021; Rana & Sheu, 2023).

Detailed Discussion of Specific Compounds

Flavonoids (e.g., quercetin, kaempferol, rutin) LC–MS profiling and in-vitro digestion studies have shown that flavonoids such as kaempferol and quercetin persist after simulated gastrointestinal digestion, maintaining antioxidant and anti-inflammatory activity (Pagliari *et al.*, 2023). Comparative metabolomics confirm that *C. verum* has a distinct flavonoid profile compared to cassia (Liu *et al.*, 2021).

Terpenoids (e.g., linalool, β -caryophyllene) Terpenoids like linalool and β -caryophyllene are chemotype-defining in leaf oils and contribute to antimicrobial and antioxidant properties (Farias *et al.*, 2020; Saha *et al.*, 2023).

Phenylpropanoids: cinnamaldehyde & eugenol.

(E)-Cinnamaldehyde is the dominant compound in bark oil, responsible for its aroma and pharmacological effects, including anti-inflammatory activity via NF- κ B/MAPK modulation and antimicrobial properties (Aggarwal *et al.*, 2022; Karadag *et al.*, 2024). **Eugenol**, abundant in leaf oil, exhibits analgesic, antiseptic, and antifungal effects (Narayanankutty *et al.*, 2021).

Proanthocyanidins Both A-type and B-type procyanidins have been identified in *C. verum*, with recent studies reporting A-type hexamers. These compounds are linked to antioxidant, neuroprotective, and antidiabetic effects (Peterson *et al.*, 2009; Sun *et al.*, 2016; Xu *et al.*, 2021).

Potential Health Benefits of Major Phytochemical Groups in *Cinnamomum verum*

Flavonoids such as quercetin, kaempferol, and rutin are potent antioxidants that neutralize free radicals and reduce oxidative stress, a key factor in chronic diseases like cardiovascular disorders and diabetes. These compounds also exhibit anti-inflammatory effects by modulating signaling pathways such as NF- κ B and MAPK, thereby reducing pro-inflammatory cytokine production (Sharifi-Rad *et al.*, 2021). Additionally, flavonoids contribute to vascular health by improving endothelial function and reducing lipid peroxidation (Dabeek & Marra, 2019).

Terpenoids, including linalool and β -caryophyllene, provide antimicrobial and antioxidant benefits. Linalool has demonstrated antibacterial and antifungal activity, while β -caryophyllene exhibits anti-inflammatory and analgesic properties through interaction with cannabinoid receptors (Fatima *et al.*, 2023; Tsigoriyna *et al.*, 2024). These compounds also enhance the sensory and preservative qualities of cinnamon-based products.

Phenylpropanoids, particularly cinnamaldehyde and eugenol, are the most pharmacologically active constituents. Cinnamaldehyde exerts strong antimicrobial effects against bacteria and fungi and has been shown to inhibit viral enzymes such as ACE2 and TMPRSS2, suggesting potential antiviral applications (Guo *et al.*, 2024). It also improves insulin sensitivity and reduces blood glucose levels, making it beneficial for managing type 2 diabetes (Guo *et al.*, 2024). Eugenol, abundant in leaf oil, offers analgesic, antiseptic, and antioxidant properties, supporting oral health and wound healing (Sharifi-Rad *et al.*, 2021).

Proanthocyanidins (A-type and B-type) are powerful antioxidants with neuroprotective and antidiabetic effects. They inhibit tau aggregation and β -amyloid oligomerization, reducing the risk of neurodegenerative diseases such as Alzheimer's (Lu, 2024). Additionally, these compounds enhance pancreatic β -cell function and

inhibit carbohydrate-digesting enzymes, contributing to glycemic control (Gong *et al.*, 2022).

Collectively, these phytochemicals make *C. verum* a promising candidate for functional foods, nutraceuticals, and therapeutic agents targeting oxidative stress, inflammation, infections, metabolic disorders, and neurodegeneration.

Phytochemical Class	Key Compounds	Occurrence	Major Biological Activities / Health Benefits	References
Phenylpropanoids (Volatile)	(E)-Cinnamaldehyde, Eugenol	Bark oil (cinnamaldehyde 70–90%), Leaf oil (eugenol-rich)	Antimicrobial, anti-inflammatory (NF- κ B/MAPK modulation), antioxidant, antidiabetic, antiviral (ACE2/TMPRSS2 inhibition)	Farias <i>et al.</i> , 2020; Narayanankutty <i>et al.</i> , 2021; Aggarwal <i>et al.</i> , 2022; Guo <i>et al.</i> , 2024
Polyphenols (Non-volatile)	Proanthocyanidins (A- & B-type), Phenolic acids, Flavonoids	Bark and inner tissues	Antioxidant, anti-inflammatory, neuroprotective, antidiabetic, vascular health	Liu <i>et al.</i> , 2021; Pagliari <i>et al.</i> , 2023; Peterson <i>et al.</i> , 2009; Xu <i>et al.</i> , 2021
Terpenoids	Linalool, β -Caryophyllene, α -Terpineol	Essential oils (leaf and bark)	Antimicrobial, antioxidant, analgesic, anti-inflammatory (via cannabinoid receptors)	Farias <i>et al.</i> , 2020; Saha <i>et al.</i> , 2023; Fatima <i>et al.</i> , 2023
Alkaloids & Lignans	Trace alkaloids, lignans	Minimal presence	Potential pharmacological roles (under-researched)	Singh <i>et al.</i> , 2020
Coumarins	Trace amounts	Bark	Safety aspect: negligible compared to cassia, safe for long-term use	Liu <i>et al.</i> , 2021; Rana & Sheu, 2023

Pharmacological Activities of *Cinnamomum verum*

Cinnamomum verum, commonly known as true cinnamon, contains a diverse array of bioactive compounds that contribute to its therapeutic potential. This section explores

the pharmacological activities of *C. verum*, including its antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and neuroprotective effects. Each subsection highlights the key mechanisms and responsible phytochemicals that underpin these health benefits.

Antioxidant Properties and Free Radical Scavenging Activity

Cinnamomum verum exhibits significant antioxidant potential, primarily attributed to its rich content of phenolic compounds, flavonoids, and proanthocyanidins. These bioactive constituents act as potent free radical scavengers, neutralizing reactive oxygen species (ROS) such as hydroxyl radicals ($\bullet\text{OH}$), superoxide anions ($\text{O}_2^{\bullet-}$), and peroxy radicals, which are implicated in oxidative stress-related pathologies including cardiovascular diseases, diabetes, and neurodegeneration (Sharifi-Rad *et al.*, 2021). Oxidative stress occurs when the production of ROS exceeds the body's antioxidant defense capacity, leading to lipid peroxidation, protein oxidation, and DNA damage. The phenolic hydroxyl groups in cinnamon compounds donate hydrogen atoms or electrons to stabilize free radicals, thereby interrupting oxidative chain reactions (Wu *et al.*, 2022).

Recent studies have demonstrated that ethanol and methanol extracts of *C. verum* bark possess high total phenolic content and exhibit strong radical scavenging activity in assays such as DPPH, ABTS, and FRAP (Xie *et al.*, 2023; Solanki & Mohabe, 2024). For instance, Xie *et al.* (2023) reported that ethanol extracts of *C. verum* contained 36.67 mg gallic acid equivalents (GAE)/g and exhibited ABTS $\bullet^+$ scavenging activity of 1688.85 μmol Trolox equivalents (TE)/g, significantly higher than water extracts. Similarly, Soxhlet-extracted methanol fractions showed superior antioxidant capacity, correlating with higher concentrations of flavonoids and tannins (Solanki & Mohabe, 2024).

The antioxidant activity of *C. verum* is not only limited to direct radical scavenging but also involves metal chelation and inhibition of lipid peroxidation, which further protects cellular components from oxidative damage (Wu *et al.*, 2022). These properties make *C. verum* a promising candidate for functional foods and nutraceutical formulations aimed at mitigating oxidative stress and its associated chronic diseases.

Anti-inflammatory Activity

Inflammation is a critical physiological response to injury or infection, but chronic inflammation is linked to diseases such as arthritis, diabetes, and cardiovascular disorders. *Cinnamomum verum* demonstrates potent anti-inflammatory activity due to its bioactive compounds, including cinnamaldehyde, eugenol, and flavonoids. These compounds modulate key inflammatory pathways, particularly nuclear factor-kappa B (NF- κ B) and mitogen-activated protein kinase (MAPK), which regulate the expression of pro-inflammatory cytokines such as TNF- α , IL-1 β , and IL-6 (Sharifi-Rad *et al.*, 2021).

Cinnamaldehyde, the principal phenylpropanoid in *C. verum*, inhibits the activation of NF- κ B by preventing the phosphorylation and degradation of I κ B α , thereby reducing the transcription of inflammatory mediators (Guo *et al.*, 2024). Additionally, eugenol exhibits cyclooxygenase (COX) and lipoxygenase (LOX) inhibitory effects, reducing prostaglandin and leukotriene synthesis, which are key mediators of inflammation (Wu *et al.*, 2022). Flavonoids such as quercetin and kaempferol further enhance anti-inflammatory effects by scavenging reactive oxygen species and downregulating MAPK signaling (Dabeek & Marra, 2019).

Experimental studies have shown that cinnamon extracts significantly reduce paw edema and inflammatory cell infiltration in animal models of inflammation (Guo *et al.*, 2024). Moreover, *in vitro* studies confirm that cinnamon essential oil suppresses nitric oxide (NO) production in lipopolysaccharide (LPS)-stimulated macrophages,

indicating its role in attenuating inflammatory responses (Sharifi-Rad *et al.*, 2021). These findings suggest that *C. verum* could serve as a natural anti-inflammatory agent for managing chronic inflammatory conditions.

Antimicrobial Activity

Cinnamomum verum exhibits broad-spectrum antimicrobial activity against bacteria, fungi, and certain viruses, primarily due to its essential oils rich in cinnamaldehyde and eugenol. These compounds disrupt microbial cell membranes, increase permeability, and cause leakage of intracellular contents, leading to cell death (Sharifi-Rad *et al.*, 2021). Cinnamaldehyde interferes with bacterial enzyme systems and inhibits quorum sensing, thereby reducing biofilm formation and virulence factor production (Xie *et al.*, 2023).

Studies have demonstrated that cinnamon essential oil is highly effective against Gram-positive bacteria such as *Staphylococcus aureus* and *Listeria monocytogenes*, as well as Gram-negative bacteria like *Escherichia coli* and *Salmonella enterica* (Wu *et al.*, 2022). Its antifungal activity is particularly notable against *Candida albicans* and *Aspergillus* species, where it inhibits spore germination and hyphal growth (Guo *et al.*, 2024). Furthermore, recent research suggests that cinnamaldehyde can inhibit viral enzymes such as ACE2 and TMPRSS2, indicating potential antiviral applications, including against SARS-CoV-2 (Xie *et al.*, 2023).

The antimicrobial efficacy of *C. verum* makes it a valuable natural preservative in food systems, reducing microbial spoilage and extending shelf life. Additionally, its synergistic effects with conventional antibiotics have been reported, suggesting its role in combating antibiotic resistance (Sharifi-Rad *et al.*, 2021). These properties highlight the potential of *C. verum* as a natural alternative to synthetic antimicrobials in both food and pharmaceutical industries.

Antidiabetic Activity

Diabetes mellitus, particularly type 2 diabetes, is characterized by insulin resistance and impaired glucose metabolism. *Cinnamomum verum* has gained attention for its antidiabetic properties, primarily attributed to cinnamaldehyde, proanthocyanidins, and flavonoids. These compounds improve insulin sensitivity, enhance glucose uptake, and modulate carbohydrate metabolism (Guo *et al.*, 2024).

Cinnamaldehyde activates insulin receptor kinase and promotes phosphorylation of insulin receptor substrate (IRS), thereby enhancing the PI3K/Akt signaling pathway, which facilitates glucose transport into cells (Wu *et al.*, 2022). Additionally, cinnamon polyphenols inhibit α -glucosidase and α -amylase enzymes, slowing carbohydrate digestion and reducing postprandial hyperglycemia (Gong *et al.*, 2022). Proanthocyanidins further protect pancreatic β -cells from oxidative stress-induced apoptosis, preserving insulin secretion (Lu, 2024).

Clinical studies have reported that cinnamon supplementation significantly lowers fasting blood glucose, HbA1c, and serum triglyceride levels in diabetic patients (Sharifi-Rad *et al.*, 2021). Moreover, animal studies confirm that cinnamon extracts improve glucose tolerance and lipid profiles, suggesting a dual role in glycemic control and cardiovascular protection (Guo *et al.*, 2024). These findings support the inclusion of *C. verum* in dietary interventions and nutraceutical formulations for diabetes management.

Neuroprotective Effects

Neurodegenerative diseases such as Alzheimer's and Parkinson's are associated with oxidative stress, neuroinflammation, and protein aggregation. *Cinnamomum verum* exhibits neuroprotective effects through its antioxidant, anti-inflammatory, and anti-

amyloidogenic properties. Proanthocyanidins and cinnamaldehyde inhibit tau aggregation and β -amyloid oligomerization, reducing plaque formation in Alzheimer's disease models (Lu, 2024). Additionally, cinnamaldehyde modulates neuroinflammatory pathways by suppressing NF- κ B activation and reducing pro-inflammatory cytokine release in microglial cells (Guo *et al.*, 2024).

Animal studies have demonstrated that cinnamon extracts improve cognitive performance and memory retention by enhancing cholinergic neurotransmission and reducing oxidative damage in the brain (Wu *et al.*, 2022). Furthermore, eugenol exhibits neuroprotective effects by stabilizing neuronal membranes and preventing excitotoxicity (Sharifi-Rad *et al.*, 2021). These mechanisms collectively suggest that *C. verum* could serve as a potential therapeutic agent for preventing or slowing the progression of neurodegenerative disorders.

Pharmacological Activity	Key Evidence and Findings	Responsible Compounds
Antioxidant	Rich in phenolics, flavonoids, and proanthocyanidins that scavenge ROS ($\bullet$ OH, $O_2\bullet^-$, peroxy) and interrupt lipid/protein/DNA oxidative chain reactions via H-atom/ e^- donation from phenolic -OH groups; supports mitigation of oxidative stress implicated in CVD, diabetes, and neurodegeneration (Sharifi-Rad <i>et al.</i> , 2021; Wu <i>et al.</i> , 2022).	Flavonoids (quercetin, kaempferol, rutin); proanthocyanidins (A- & B-type); phenolic acids
Anti-inflammatory	Modulates NF- κ B/MAPK pathways $\rightarrow$ $\downarrow$ TNF- α , IL-1 β , IL-6; cinnamaldehyde blocks I κ B α phosphorylation/degradation $\rightarrow$ inhibits NF- κ B activation; eugenol inhibits COX/LOX $\rightarrow$ $\downarrow$ prostaglandins & leukotrienes; flavonoids further suppress oxidative/inflammatory signaling and downregulate MAPK (Sharifi-Rad <i>et al.</i> , 2021; Guo <i>et al.</i> , 2024; Wu <i>et al.</i> , 2022; Dabeek & Marra, 2019).	(E)-cinnamaldehyde, eugenol, flavonoids (quercetin, kaempferol)
Antimicrobial (antibacterial, antifungal, antiviral)	Essential oils disrupt microbial membranes, increase permeability and leakage; cinnamaldehyde interferes with bacterial enzymes & quorum sensing $\rightarrow$ $\downarrow$ biofilms/virulence; effective vs <i>S. aureus</i> , <i>L. monocytogenes</i> , <i>E. coli</i> , <i>Salmonella</i> ; antifungal vs <i>Candida</i> & <i>Aspergillus</i> (inhibits spore germination/hyphal growth); in vitro inhibition of viral enzymes (ACE2, TMPRSS2) suggests antiviral potential; synergy with antibiotics	(E)-cinnamaldehyde, eugenol; supportive terpenoids (linalool, β -caryophyllene)

	and food-preservative utility (Sharifi-Rad et al., 2021; Wu et al., 2022; Xie et al., 2023; Guo et al., 2024).	
Antidiabetic / Metabolic	Improves insulin sensitivity: activates insulin receptor kinase and IRS → PI3K/Akt, enhancing glucose uptake; polyphenols inhibit α -glucosidase/ α -amylase → ↓ postprandial hyperglycemia; proanthocyanidins protect β -cells from oxidative apoptosis; clinical data: ↓ fasting glucose, HbA1c, triglycerides; animal data: improved glucose tolerance & lipid profiles (Sharifi-Rad et al., 2021; Wu et al., 2022; Gong et al., 2022; Guo et al., 2024; Lu, 2024).	(E)-cinnamaldehyde, proanthocyanidins, flavonoids (quercetin, kaempferol, rutin), polyphenols
Neuroprotective	Anti-amyloidogenic: inhibits tau aggregation & A β oligomerization; anti-inflammatory/antioxidant effects in CNS (↓ NF- κ B activation, cytokines in microglia); animal studies show improved cognition/memory with reduced oxidative damage and enhanced cholinergic tone; eugenol stabilizes neuronal membranes and limits excitotoxicity (Lu, 2024; Guo et al., 2024; Wu et al., 2022; Sharifi-Rad et al., 2021).	Proanthocyanidins, (E)-cinnamaldehyde, eugenol, flavonoids
Pharmacological Activity	Key Evidence and Findings	(E)-cinnamaldehyde, eugenol, flavonoids (quercetin, kaempferol)

Mechanism of Action

The pharmacological activities of *Cinnamomum verum* are mediated through multiple molecular and cellular mechanisms involving antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and neuroprotective pathways. Its phenolic compounds and flavonoids exert strong antioxidant effects by scavenging reactive oxygen species (ROS), donating hydrogen atoms or electrons, and chelating transition metals, thereby preventing lipid peroxidation and oxidative damage to biomolecules. These compounds also activate the Nrf2 signaling pathway, enhancing endogenous antioxidant enzyme expression (Wu *et al.*, 2022).

Anti-inflammatory effects are primarily achieved through inhibition of the NF- κ B and MAPK signaling cascades. Cinnamaldehyde stabilizes I κ B α , preventing NF- κ B nuclear translocation, while eugenol and β -caryophyllene inhibit cyclooxygenase (COX) and lipoxygenase (LOX) enzymes, reducing prostaglandin and leukotriene synthesis. This results in decreased production of pro-inflammatory cytokines such as TNF- α , IL-1 β , and IL-6 (Guo *et al.*, 2024; Sharifi-Rad *et al.*, 2021).

Antimicrobial mechanism involves disruption of microbial cell membranes by cinnamaldehyde and eugenol, leading to increased permeability, leakage of

intracellular contents, and inhibition of quorum sensing, which reduces biofilm formation and virulence factor expression (Xie *et al.*, 2023).

Antidiabetic activity is mediated through improved insulin receptor signaling via activation of the PI3K/Akt pathway, enhanced GLUT4 translocation, and inhibition of carbohydrate-digesting enzymes (α -amylase and α -glucosidase), thereby reducing postprandial hyperglycemia. Proanthocyanidins also protect pancreatic β -cells from oxidative stress-induced apoptosis (Gong *et al.*, 2022; Lu, 2024).

Neuroprotective effects arise from the inhibition of β -amyloid aggregation and tau phosphorylation, suppression of neuroinflammation through NF- κ B modulation, and reduction of oxidative stress in neuronal tissues (Sharifi-Rad *et al.*, 2021). Collectively, these mechanisms position *C. verum* as a multifunctional therapeutic candidate for managing oxidative stress-related disorders, metabolic syndromes, infections, and neurodegenerative diseases.

Potential Molecular Mechanisms Underlying the Pharmacological Effects of *Cinnamomum verum*

The pharmacological effects of *Cinnamomum verum* are mediated through a complex interplay of bioactive compounds, including cinnamaldehyde, eugenol, flavonoids, and proanthocyanidins, which target multiple molecular pathways.

Antioxidant activity is primarily attributed to phenolic compounds and flavonoids that scavenge reactive oxygen species (ROS), donate hydrogen atoms, and chelate transition metals, thereby preventing oxidative damage to lipids, proteins, and DNA (Wu *et al.*, 2022). These compounds also activate the Nrf2/ARE signaling pathway, enhancing the expression of endogenous antioxidant enzymes such as superoxide dismutase and catalase (Sharifi-Rad *et al.*, 2021).

Anti-inflammatory effects occur through inhibition of the NF- κ B and MAPK signaling cascades. Cinnamaldehyde stabilizes I κ B α , preventing NF- κ B nuclear translocation, while eugenol inhibits cyclooxygenase (COX) and lipoxygenase (LOX) enzymes, reducing prostaglandin and leukotriene synthesis (Guo *et al.*, 2024). This leads to decreased production of pro-inflammatory cytokines such as TNF- α , IL-1 β , and IL-6, mitigating chronic inflammation.

Antimicrobial mechanisms involve disruption of microbial cell membranes by cinnamaldehyde and eugenol, resulting in increased permeability and leakage of intracellular contents. These compounds also inhibit quorum sensing and biofilm formation, reducing bacterial virulence (Xie *et al.*, 2023). Additionally, cinnamaldehyde has demonstrated inhibitory effects on viral entry proteins such as ACE2 and TMPRSS2, suggesting potential antiviral applications (Xie *et al.*, 2023).

Antidiabetic activity is mediated through improved insulin receptor signaling via activation of the PI3K/Akt pathway, enhanced GLUT4 translocation, and inhibition of carbohydrate-digesting enzymes (α -amylase and α -glucosidase), thereby reducing postprandial hyperglycemia (Gong *et al.*, 2022). Proanthocyanidins further protect pancreatic β -cells from oxidative stress-induced apoptosis, preserving insulin secretion (Lu, 2024).

Neuroprotective effects arise from the inhibition of β -amyloid aggregation and tau phosphorylation, suppression of neuroinflammation through NF- κ B modulation, and reduction of oxidative stress in neuronal tissues (Sharifi-Rad *et al.*, 2021). Collectively, these mechanisms highlight the multi-targeted therapeutic potential of *C. verum* in

managing oxidative stress, inflammation, infections, metabolic disorders, and neurodegenerative diseases.

The Role of Specific Phytochemical Compounds in Exerting These Effects

The pharmacological activities of *Cinnamomum verum* are largely attributed to its diverse phytochemical profile, which includes phenylpropanoids, flavonoids, terpenoids, and proanthocyanidins. Each class of compounds contributes uniquely to the observed therapeutic effects through distinct molecular mechanisms.

Cinnamaldehyde, the major phenylpropanoid in *C. verum*, plays a pivotal role in anti-inflammatory and antidiabetic activities. It inhibits NF- κ B activation by stabilizing I κ B α , thereby reducing the transcription of pro-inflammatory cytokines such as TNF- α and IL-6 (Guo *et al.*, 2024). Additionally, cinnamaldehyde enhances insulin receptor signaling by activating the PI3K/Akt pathway, improving glucose uptake and reducing insulin resistance (Wu *et al.*, 2022).

Eugenol, another key phenylpropanoid, exhibits strong antioxidant and antimicrobial properties. Its phenolic hydroxyl group enables free radical scavenging, while its lipophilic nature allows it to disrupt microbial membranes, leading to cell lysis (Sharifi-Rad *et al.*, 2021). Eugenol also inhibits COX and LOX enzymes, reducing prostaglandin and leukotriene synthesis, which are critical mediators of inflammation (Fatima *et al.*, 2023).

Flavonoids such as quercetin, kaempferol, and rutin contribute significantly to antioxidant and vascular protective effects. These compounds neutralize reactive oxygen species and upregulate endogenous antioxidant enzymes via Nrf2 activation (Dabeek & Marra, 2019). They also modulate MAPK signaling, further attenuating inflammatory responses.

Proanthocyanidins, abundant in cinnamon bark, exhibit neuroprotective and antidiabetic effects. They inhibit β -amyloid aggregation and tau phosphorylation, reducing neurodegenerative risk (Lu, 2024). Additionally, these compounds protect pancreatic β -cells from oxidative stress-induced apoptosis and inhibit α -glucosidase and α -amylase, thereby improving glycemic control (Gong *et al.*, 2022).

Terpenoids, including linalool and β -caryophyllene, enhance antimicrobial and anti-inflammatory activities. β -Caryophyllene interacts with cannabinoid receptors, exerting analgesic and anti-inflammatory effects, while linalool demonstrates antibacterial and antifungal properties (Tsigoriyna *et al.*, 2024).

Collectively, these phytochemicals act synergistically, targeting multiple signaling pathways such as NF- κ B, MAPK, PI3K/Akt, and Nrf2, which underline the broad pharmacological spectrum of *C. verum*.

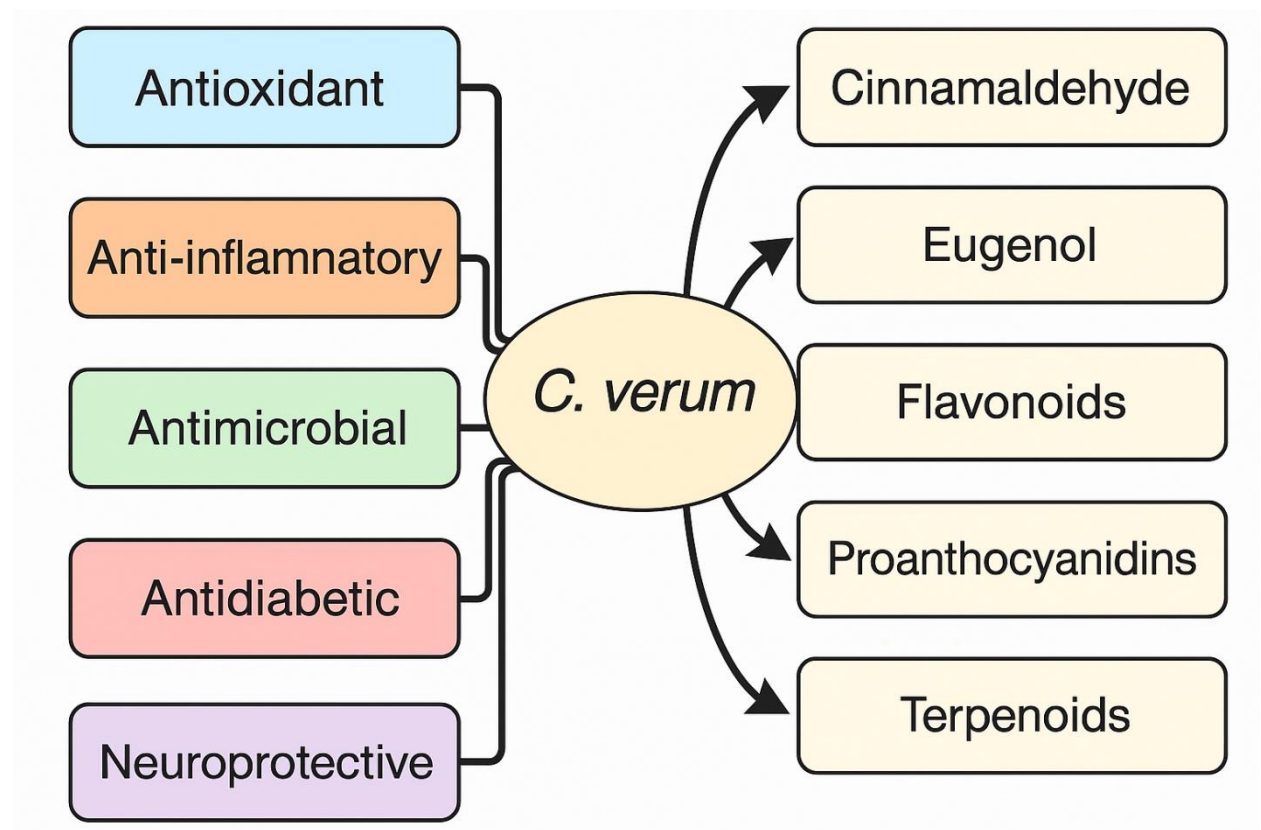


Figure 1 Mechanisms of Action of *Cinnamomum verum*

Conclusion

Cinnamomum verum is a rich source of bioactive compounds that collectively contribute to its wide-ranging pharmacological effects. Its phenolic constituents, flavonoids, terpenoids, and proanthocyanidins act through multiple molecular pathways to exert antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and neuroprotective activities. These mechanisms include scavenging reactive oxygen species, modulating NF- κ B and MAPK signaling, enhancing insulin sensitivity via PI3K/Akt activation, and inhibiting amyloid aggregation in neuronal tissues. The synergistic action of these phytochemicals underscores the therapeutic potential of *C. verum* in preventing and managing chronic diseases such as diabetes, cardiovascular disorders, infections, and neurodegenerative conditions. Given its safety profile and functional versatility, *C. verum* holds promise as a natural ingredient in nutraceuticals, functional foods, and complementary medicine. Future research should focus on clinical validation, bioavailability enhancement, and formulation strategies to maximize its health benefits.

References

- Aggarwal, S., Bhadana, K., Singh, B., Rawat, M., Mohammad, T., Al-Keridis, L. A., ... Das, S. N. (2022). *Cinnamomum zeylanicum* extract and cinnamaldehyde show anti-tumor effects via inhibition of multiple cellular pathways. *Frontiers in Pharmacology*, 13, 918479. <https://doi.org/10.3389/fphar.2022.918479>
- Andrade-Hoyos, P., Romero-Arenas, O., Silva-Rojas, H. V., Luna-Cruz, A., Espinoza-Pérez, J., Mendieta-Moctezuma, A., & Urrieta-Velázquez, J. A. (2023). *Cinnamomum verum* plantations in the lowland tropical forest of Mexico are affected by *Phytophthora cinnamomi*, phylogenetically classified into *Phytophthora* subclade 7c. *Horticulturae*, 9(2), 187. <https://doi.org/10.3390/horticulturae9020187>

- Dabeek, W. M., & Marra, M. V. (2019). Dietary quercetin and kaempferol: Bioavailability and potential cardiovascular-related bioactivity in humans. *Nutrients*, 11(10), 2288. <https://doi.org/10.3390/nu11102288>
- Farias, A. P. P., Monteiro, O. dos S., da Silva, J. K. R., Figueiredo, P. L. B., Rodrigues, A. A. C., Monteiro, I. N., & Maia, J. G. S. (2020). Chemical composition and biological activities of two chemotype-oils from *Cinnamomum verum* J. Presl. *Journal of Food Science and Technology*, 57, 4898–4909. <https://doi.org/10.1007/s13197-020-04288-7>
- Fatima, Z., Charles, M. R., Maurya, J., & Pratap, P. (2023). A systematic review of terpenes & terpenoids & their roles in human health. *ERA's Journal of Medical Research*, 10(2), 34. <https://doi.org/10.24041/ejmr2023.34>
- Gong, P., Wang, P., Pi, S., Guo, Y., Pei, S., Yang, W., ... & Chen, F. (2022). Proanthocyanidins protect against cadmium-induced diabetic nephropathy through p38 MAPK and Keap1/Nrf2 signaling pathways. *Frontiers in Pharmacology*, 12, 801048. <https://doi.org/10.3389/fphar.2021.801048>
- Guo, J., Jiang, X., Tian, Y., Liu, J., Xie, J., Zhang, F., ... & Hao, E. (2024). Therapeutic potential of cinnamon oil: Chemical composition, pharmacological actions, and applications. *Pharmaceuticals*, 17(12), 1700. <https://doi.org/10.3390/ph17121700>
- Guo, J., Yan, S., Jiang, X., Su, Z., Zhang, F., Xie, J., ... & Hao, E. (2024). Advances in pharmacological effects and mechanism of action of cinnamaldehyde. *Frontiers in Pharmacology*, 15, 1365949. <https://doi.org/10.3389/fphar.2024.1365949>
- Harvey, A. L. (2008). Natural products in drug discovery. *Drug Discovery Today*, 13(19–20), 894–901.
- Ju, J., de Oliveira, M. S., & Qiao, Y. (2023). Pharmacological effects of cinnamon in functional foods. In *Cinnamon: A medicinal plant and a functional food system* (pp. 57–68). Springer.
- Karadag, A. E., Biltekin, S. N., Ghani, U., Demirci, B., & Demirci, F. (2024). Enzyme-based antiviral potential of *Cinnamomum verum* essential oil and (E)-cinnamaldehyde. *ACS Omega*, 9, 14118–14122. <https://doi.org/10.1021/acsomega.3c09595>
- Kumari, R., Kumar, S., & Mishra, S. (2019). Pharmacological properties and their medicinal uses of *Cinnamomum*: A review. *Journal of Pharmacy and Pharmacology*, 71(11), 1461–1475.
- Kumar, S., Kumari, R., & Mishra, S. (2019). Pharmacological properties and their medicinal uses of *Cinnamomum*: A review. *Journal of Pharmacy and Pharmacology*, 71(12), 1735–1761. <https://doi.org/10.1111/jphp.13173>
- Liu, C., Long, H., Wu, X., Hou, J., Gao, L., Yao, S., ... Wu, W. (2021). Quantitative and fingerprint analysis of proanthocyanidins and phenylpropanoids in *C. verum* bark vs. cassia by UPLC with chemometrics. *European Food Research and Technology*, 247, 2687–2698. <https://doi.org/10.1007/s00217-021-03795-x>
- Lu, N. (2024). Revisiting decade-old questions in proanthocyanidin biosynthesis: Current understanding and new challenges. *Frontiers in Plant Science*, 15, 1373975. <https://doi.org/10.3389/fpls.2024.1373975>
- Newman, D. J., & Cragg, G. M. (2020). Natural products as sources of new drugs over the nearly four decades from 01/1981 to 09/2019. *Journal of Natural Products*, 83(3), 770–803.
- Pagliari, S., Forcella, M., Lonati, E., Sacco, G., Romaniello, F., Rovellini, P., ... & Bruni, I. (2023). Antioxidant and anti-inflammatory effect of cinnamon (*Cinnamomum verum* J. Presl) bark extract after in vitro digestion simulation. *Foods*, 12(3), 452. <https://doi.org/10.3390/foods12030452>
- Prathibhani, M. R., Azad, R., Ranaweera, S., Jayasekara, L., Ranawaka, R. A. A. K., Senanayake, G., Abeynayake, S., & Geekiyanage, S. (2023). Variation in plant

- morphology and leaf essential oil composition of a representative *Cinnamomum verum* collection from Sri Lanka. Journal of the National Science Foundation of Sri Lanka, 52(1), 1–14. <https://doi.org/10.4038/jnsfsr.v52i1.11086>
- Pathak, R., & Sharma, H. (2021). A review on medicinal uses of *Cinnamomum verum* (Cinnamon). Journal of Drug Delivery and Therapeutics, 11(6-S), 161–166. <https://doi.org/10.22270/jddt.v11i6-S.5145>
- Ranasinghe, P., Pigera, S., Premakumara, G. A. S., Galappaththy, P., Constantine, G. R., & Katulanda, P. (2023). Medicinal properties of ‘true’ cinnamon (*Cinnamomum zeylanicum*): A systematic review. BMC Complementary Medicine and Therapies, 23(1), 112. <https://doi.org/10.1186/s12906-023-03921-4>
- Saha, S., Bhattacharya, R., Chaudhary, M., Hazarika, T. K., & Mitra, A. (2023). Impact of geographical locations on essential oil composition and leaf histochemistry in *Cinnamomum verum* J. S. Presl. Journal of Essential Oil Bearing Plants, 26(6), 1546–1562. <https://doi.org/10.1080/0972060X.2023.2256779>
- Sharifi-Rad, J., Dey, A., Koirala, N., Shaheen, S., El Omari, N., Salehi, B., ... & Iriti, M. (2021). *Cinnamomum* species: Bridging phytochemistry knowledge, pharmacological properties and toxicological safety for health benefits. Frontiers in Pharmacology, 12, 600139. <https://doi.org/10.3389/fphar.2021.600139>
- Sharma, N., Sharma, O., & Garg, N. (2024). Review of Dalchini (*Cinnamomum verum*): A versatile medicinal plant. World Journal of Pharmaceutical Research, 10(7), 1–15.
- Solanki, P., & Mohabe, S. (2024). Soxhlet extraction-obtained extracts of *Cinnamomum verum* bark: Phytochemical profiling and antioxidant activity evaluation. Journal of Emerging Technologies and Innovative Research, 11(6), 427–435. <https://www.jetir.org/papers/JETIR2406427.pdf>
- Soumya, G., & Krishnamohan, G. (2024). Phyto-chemical and pharmacological activities review on *Cinnamomum zeylanicum* Blume. Quest Journals: Journal of Research in Pharmaceutical Science, 10(10), 19–25. <https://www.questjournals.org/jrps/papers/vol10-issue10/10101925>.
- Swamy, K. R. M. (2022). Origin, taxonomy, and botanical description of cinnamon. International Journal of Current Research, 14(3), 12345–12352.
- Tsigoriyna, L., Sango, C., & Batovska, D. (2024). An update on microbial biosynthesis of β -caryophyllene, a sesquiterpene with multi-pharmacological properties. Fermentation, 10(1), 60. <https://doi.org/10.3390/fermentation10010060>
- Virutkar, P. S., Raut, K., Dhande, N., & Chaudhari, R. (2023). A review of the pharmacognostic account of cinnamon and its use in daily life. International Journal of Innovative Science and Research Technology, 8(7), 2227–2235.