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Antioxidant, Anti-Inflammatory, And Analgesic Properties Of Cinnamon Bark

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Abstract

Cinnamon bark, derived from the Cinnamomum species, is renowned for its diverse pharmacological properties, including antioxidant, anti-inflammatory, and analgesic effects. This review examines the bioactive compounds present in cinnamon bark, such as essential oils (primarily cinnamaldehyde), polyphenols, and flavonoids, which contribute to its therapeutic potential. The antioxidant properties of cinnamon are primarily attributed to its ability to scavenge free radicals and neutralize oxidative stress, thereby protecting cells from damage. Additionally, cinnamon exhibits significant anti-inflammatory activity by modulating inflammatory pathways, including the inhibition of key mediators such as nitric oxide and pro-inflammatory cytokines. Its analgesic effects, demonstrated through modulation of nociceptive pathways, further enhance its utility in pain management. Both in vitro and in vivo studies support these findings, showing that cinnamon's bioactive constituents exert their effects through various molecular mechanisms, including regulation of enzymes, gene expression, and antioxidant systems. Despite its widespread use in traditional medicine, modern clinical evidence is still limited, with a need for further studies to establish clear therapeutic guidelines. While generally considered safe at recommended dosages, excessive consumption of cinnamon, particularly varieties rich in coumarin, can lead to adverse effects such as liver toxicity. The synergistic use of cinnamon with other herbal remedies like turmeric and ginger is also explored, highlighting enhanced therapeutic benefits. Given its broad pharmacological effects, cinnamon bark represents a promising natural remedy for managing chronic diseases associated with oxidative stress, inflammation, and pain, warranting further clinical investigations and applications in modern medicine.

Keywords-: Cinnamon bark ,Antioxidant properties ,Anti-inflammatory effects ,Analgesic properties,Herbal medicine.

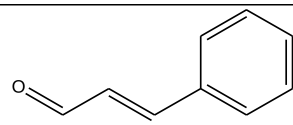
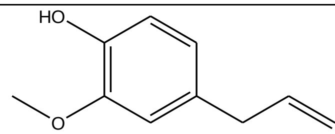
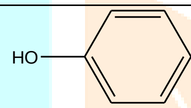
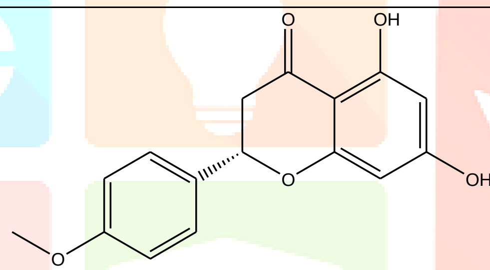
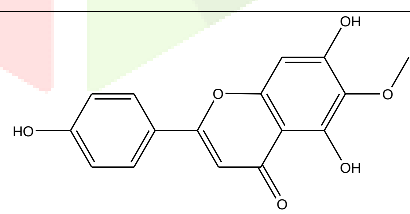
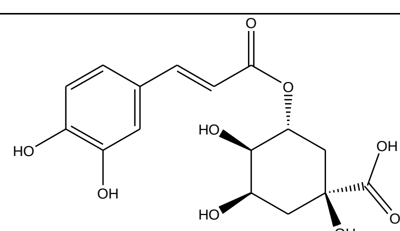
1. Introduction

Cinnamon is a flowering plant of the genus Cinnamomum within the family Lauraceae [1]. It is native to the Middle East and South Asia. Cinnamon is rich in essential oils, polyphenols, and flavonoids [2]. It has been widely used in food preparations in Asian and Arabian countries and also plays an important role in traditional medicine [3]. Cinnamon exhibits a range of biological and pharmacological properties, such as anti-diabetic, anticholesterolemic, antibacterial, antifungal, antioxidant, antimutagenic, anti-inflammatory, and cardiovascular-disease-protective properties. The antioxidant property of cinnamon is gaining increasing attention, promoting its use as a potential nutraceutical. [4][5][6].Cinnamon is an evergreen tree native to Sri Lanka, Madagascar, Seychelles, and Tanzania. The evergreen trees grow up to 10–15 meters tall and form a dense, bushy crown [7].The bark is used as seasoning and flavoring material for food and is also incorporated into traditional and modern medicines. These features prompted the present review on the antioxidant, anti-inflammatory, and analgesic properties of cinnamon bark.The phytochemical composition of cinnamon includes essential oils such as cinnamaldehyde, cinnamate, and cinnamic acid, as well as polyphenols and flavonoids, which are critical to its medicinal attributes [8][9][10].

3. Phytochemical Composition of Cinnamon

Cinnamon bark contains various bioactive compounds, including essential oil, polyphenols, and flavonoids. Cinnamon essential oil is composed of approximately 80% cinnamaldehyde, along with substances such as eugenol and phenol, and is commonly employed as a flavoring agent [11]. The polyphenol and flavonoid contents are key contributors to cinnamon's multifunctional pharmacological effects, encompassing antioxidant, anti-inflammatory, and anticancer activities. The leaf oil similarly exhibits considerable antioxidant activity attributed to its high phenolic content [12]. Among the most abundant phenolics in leaf oil are isosakuranetin, hispidulin, and chlorogenic acid. Isosakuranetin, a flavonoid also found in citrus fruits, possesses antimicrobial, antioxidant, anticancer, and neuroprotective properties; hispidulin, prevalent in many medicinal plants, is noted for its antioxidant effects; and chlorogenic acid, present in high concentrations in coffee and tea, exhibits potent antioxidant and various pharmacological activities. The antioxidant capacity of these plant oils correlates with their elevated reducing power, enabling the mitigation of oxidative stress by neutralizing reactive oxygen species [13].

Table 1. Constituent Details and Pharmacological Properties of Plant Bark and Leaf Compounds

Constituent	Structure	Source (Bark/Leaf)	Properties / Pharmacological Activities
Cinnamaldehyde		Bark (≈80%)	Flavoring agent, antimicrobial, antioxidant
Eugenol		Bark	Antioxidant, antimicrobial, analgesic
Phenol		Bark	Antioxidant, antiseptic
Isosakuranetin		Leaf oil	Antimicrobial, antioxidant, anticancer, neuroprotective
Hispidulin		Leaf oil	Antioxidant, anti-inflammatory
Chlorogenic acid		Leaf oil	Potent antioxidant, anti-inflammatory, metabolic regulation

3.1. Essential Oils

Cinnamon oil consists of a mixture of various compounds, including hydrocarbons, aldehydes, alcohols, esters, and phenols [14]. The main components of the essential oil extracted from cinnamon bark are cinnamaldehyde, trans-cinnamaldehyde, and O-methoxycinnamaldehyde. Cinnamaldehyde accounts for 50 to 90% of the essential oil's composition and is primarily responsible for its characteristic aroma. The compound is biosynthesized via the metabolism of the amino acid phenylalanine in the plant and has been shown to possess anticholinesterase activity and excellent antioxidant properties. Cineol, which comprises 11 to 22% of the essential oil, has concentrations below 3.5% in aqueous extracts but rises to approximately 60% in cellulose pellicle extracts. Eugenol, representing approximately 1% of cinnamon bark oil, is a phenylpropanoid derived from guaiacol that demonstrates notable antioxidant properties. Beta-caryophyllene is another constituent present at less than 10%, contributing a desirable aroma to the oil. Other compounds that may be present include coumarin, cinnamyl methyl ether, 2-methoxycinnamaldehyde, α-copaene, β-elemene, α-humulene, α-cadinene, γ-muurolene, eugenyl acetate, borneol, and methyl eugenol [15]. The composition of volatile metabolites in cinnamon bark appears to be influenced by the extraction system employed [16][17].

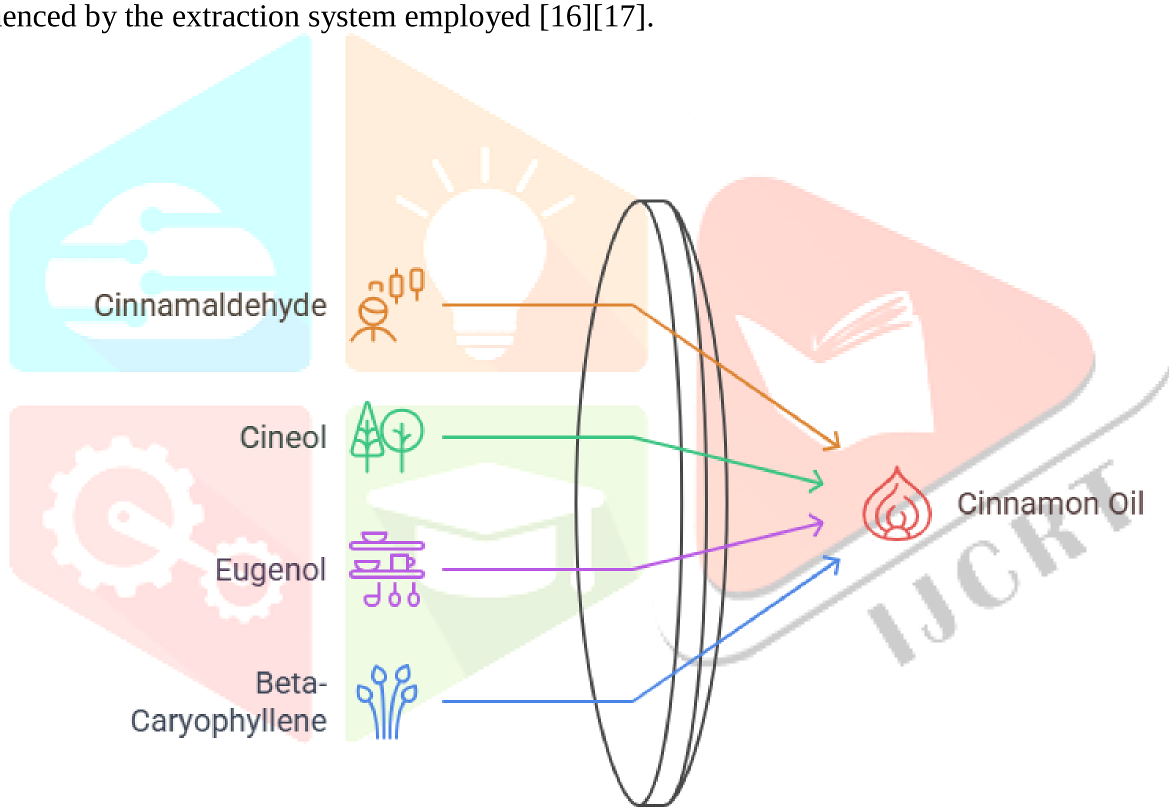


Fig 1. Composition of Cinnamon Oil

3.2. Polyphenols

One of the key sources of the antioxidant power of cinnamon is the polyphenols present in the bark of its various species [3]. Cinnamon polyphenols like polymeric polyphenols and A-type polymers may also exhibit anti-inflammatory activity and insulin-like biological activity [18]. Cinnamon extracts and essential oils contain active components that show anti-inflammatory effects in in vitro and in vivo models. Several studies suggest anti-inflammatory effects of polyphenols from fruits and berries, such as blueberry proanthocyanidins, cranberry proanthocyanidins, and grape seed proanthocyanidins, which also have potential for the treatment of periodontal diseases. Cinnamomum cassia bark, used as dietary supplement in the treatment of inflammation-related conditions, contains large amounts of proanthocyanidins. Experimental data on the structural analysis of the proanthocyanidins from the fresh bark of C. cassia reveal several A-type proanthocyanidins as the major polymers [19][20][21].

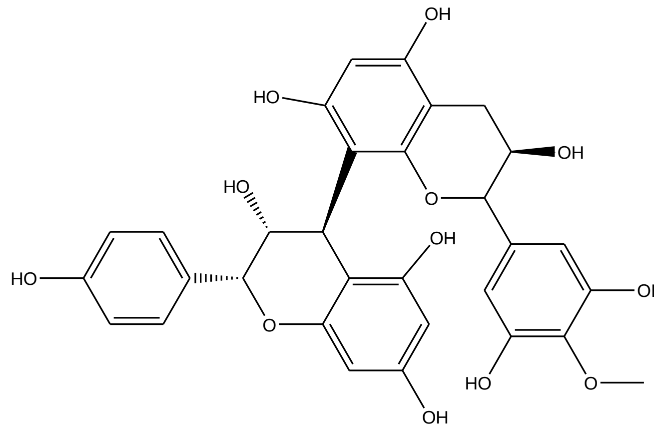


Fig 2. Proanthocyanidins

3.3. Flavonoids

Flavonoids are a large family of low molecular weight plant natural products that serve dual purposes as potent antioxidants and mediators of cell signalling events [3]. Flavonoids occur widely among the angiosperms and have been shown to provide protection to tissues exposed to UV by suppressing the formation of free radicals that lead to lipid peroxidation in cell membranes [18]. In plants, the parent flavonoid skeleton is synthesized from the acetate and shikimate pathways, leading to the cinnamic acids and phenylpropanoids. The polyphenolic acid derivatives subsequently undergo condensation with malonyl-coA to form the cyclic diphenylpropane skeleton that serves as the precursor of all known flavonoids and iso-flavonoids [22]. The more common flavonoid subclasses include chalcones, flavanones, flavones, flavonols and flavanols. The known naturally occurring flavonoids from cinnamon bark include quercetin and kaempferol that are well-distributed among the plant species [23][24][25].

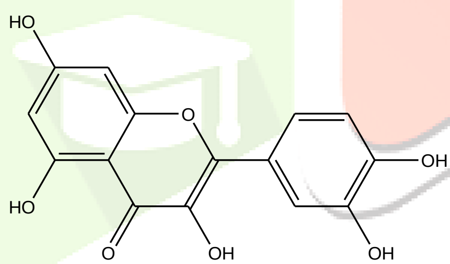


Fig 3. Quercetin

4. Antioxidant Properties of Cinnamon

Antioxidant properties refer to the mechanisms through which a compound hinders the oxidation of cellular structures, thereby mitigating free radical-induced damage [26][27]. Cinnamon exhibits such potential through its capacity to intercept free radicals, facilitated by the action of its polyphenols and phenolic compounds that can donate electrons or hydrogen atoms to neutralize reactive species. These polyphenols influence enzymatic activities, promote gene expression, and participate in the chelation of metal ions, offering additional protective roles. Both in vivo and in vitro studies corroborate the antioxidant effects attributed to cinnamon [28][29].

4.1. Mechanisms of Action

The mechanisms underlying the therapeutic properties of cinnamon bark have been examined through in vitro and in vivo models, generally encompassing the modulation of antioxidative, anti-inflammatory, and analgesic pathways [30].Cinnamon is enriched with essential oils, polyphenols, and flavonoids that contribute to its pharmacological effects. The antioxidant potential of cinnamon is often attributed to the strong free-radical scavenging capacity of its bioactive constituents. Evidence obtained from both in vivo and in vitro investigations supports the characteristic signalling cascades invoked following exposure to the various phytochemicals contained in the bark [31]. The anti-inflammatory properties of cinnamon ordinarily involve the regulation of signalling networks through the diverse phytochemical profile of the bark, producing distinct effects on a variety of physiological pathways. Investigations into the analgesic activities of cinnamon demonstrate modulation of nociceptive pathways, which is consistent with the traditional use of the spice as a pain reliever. Other health benefits of cinnamon bark are commonly linked with its potential to act as complementary medicine alongside other phytochemical-rich herbal remedies, including turmeric and ginger. Cinnamon is generally well tolerated; nevertheless, some side effects can arise from excessive consumption, with maximum recommended dosages typically in the range of 1–4 g per day [32].

Fig 4. Health Benefits and Considerations of Cinnamon Bark

4.2. In Vivo Studies

Topical application of cinnamon-derived compounds has demonstrated significant anti-inflammatory effects, including inhibition of nitric oxide (NO) production and pro-inflammatory mediators. Mechanistic studies reveal that cinnamic aldehyde, the principal constituent of cinnamon leaf oil, modulates macrophage-mediated inflammatory signaling pathways [33]. In models of formalin-induced nociception, cinnamon essential oil exhibited analgesic activity predominantly during the inflammatory phase of pain, aligning with its anti-inflammatory properties [34].

4.3. In Vitro Studies

Hazrat Ali et al. reported that cinnamon possesses potent free radical scavenging activity in vitro. Elements including polyphenols and flavonoids relate to the antioxidant function exerted by cinnamon. Premakumara et al. [35] found that aqueous extracts of cinnamon inhibited HMG-CoA reductase, lipase, cholesterol esterase, and cholesterol micellization; the extracts also bound bile acids in vitro. The compounds responsible for this inhibition remain unknown but may include cinnamate (trans-cinnamic acid), which has been suggested to act as an HMG-CoA reductase inhibitor by binding directly to the enzyme's active site. Kaushalya et al. [36] determined 3.25, 6.02, and 4.23 mg gallic acid equivalents/g total phenol content and 2.44, 2.54, and 2.08 mg catechin equivalents/g of total flavonoid content of methanol, ethanol, and acetone bark extracts, respectively (dry basis). The methanol extract's antioxidant capacity increased significantly with concentration. These findings suggest that cinnamon bark extracts could serve as natural agents for managing oxidative damage and oxidative stress-related diseases [37].

5. Anti-inflammatory Properties of Cinnamon

Numerous inflammatory pathways are regulated by cinnamon. Clinical and animal studies confirm these anti-inflammatory effects, consistent with its antioxidant properties [30].

5.1. Inflammatory Pathways

Inflammation is the organism's protective biological response to tissue injury or destruction of homeostasis. This response involves increased permeability of blood vessels and migration of polymorphonuclear leukocytes to the site of injury, which leads to oedema. It is accompanied by an upregulation in the expression of enzymes and signalling proteins, including inducible nitric oxide synthase (iNOS), which produces large amounts of NO (nitric oxide) [37]. Lipopolysaccharide (LPS), a component of the outer membrane of gram-negative bacteria, is the most commonly used endotoxin for stimulating the innate immune system in both in vitro and in vivo models. LPS induces the production of a variety of inflammatory mediators that include NO, tumour-necrosis factor-α (TNF-α) and interleukin-6. Carrageenan-induced oedema in animals is one of the most commonly used models for evaluating the anti-inflammatory properties of natural products. Injection of carrageenan results in the local infiltration of phagocytes releasing free radicals and other inflammatory mediators. Inflammation is highly associated with other chronic diseases such as asthma, rheumatoid arthritis, inflammatory bowel disease, atherosclerosis, Alzheimer's disease and certain types of cancer. The accumulation of antioxidant enzymes superoxide dismutase (SOD), catalase and glutathione peroxidase (GPx) protect tissues from oxidative stress during inflammation. Faulty or low functioning antioxidant systems can result in inflammatory and cancer diseases. Many natural products that enhance the activities of enzymatic antioxidants have been studied for their anti-inflammatory effects. The active components identified in C. cassia bark included coumarin, cinnamic acid, cinnamaldehyde and other cinnamyl derivatives. Cinnamaldehyde was shown to be the most potent anti-inflammatory compound with effects on LPS-stimulated RAW264.7 cells and carrageenan-induced paw oedema in mice. The anti-inflammatory action of cinnamaldehyde appears to work by the regulation of iNOS, COX-2, NF-κB and the enzymatic antioxidant status [38][39][40].

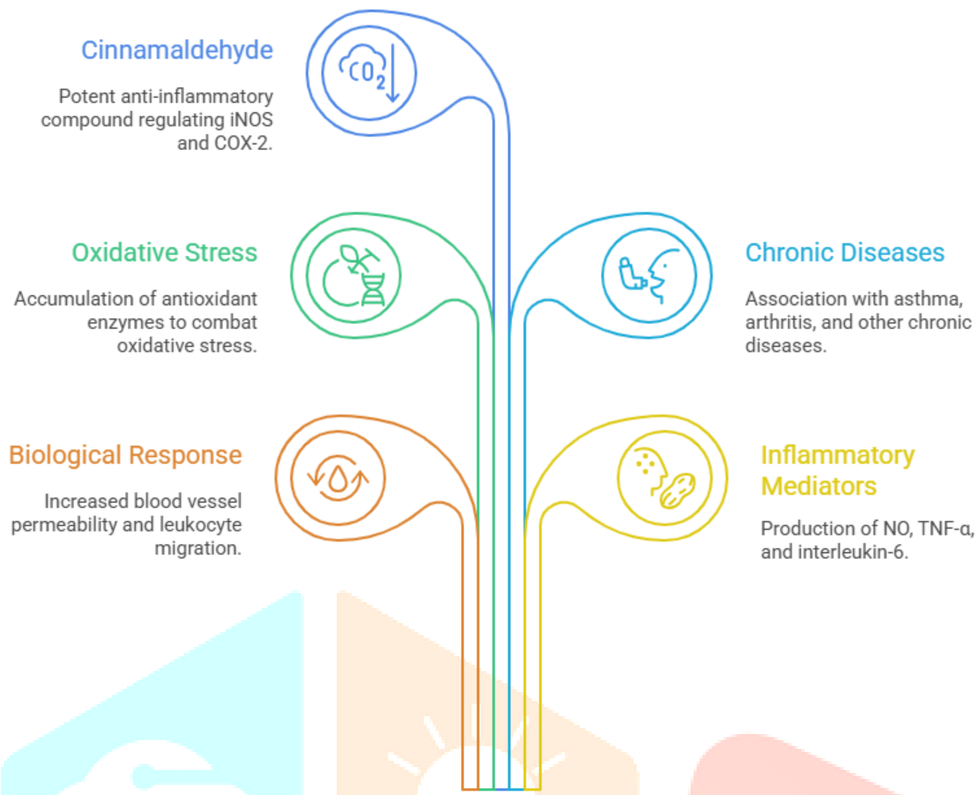


Fig 5. Mechanism of inflammation

5.2. Clinical Evidence

Although popular uses of cinnamon in human subjects have been proposed for the treatment of respiratory tract infections, dyspepsia, diarrhoea, and appetite loss, the reported clinical evidence is rather limited to substantiate these traditional uses.

One study concerning the efficacy of C. cassia in healthy adult volunteers revealed that oral administration of cinnamon powder for 60 days was able to induce a significant decrease in blood levels of malondialdehyde and red blood cells sedimentation rate, indicating a decrease of oxidative stress and inflammation . Another investigation reported a reduction of tumour necrosis factor alpha levels in unhealthy volunteers following cinnamon powder consumption [41].

Administration of a single oral dose of a cinnamon extract containing 2.1% cinnamaldehyde to healthy subjects reduced prostaglandin E2 production after exposure to ultraviolet light, substantiating its topical anti-inflammatory efficacy [42]. Pain management constitutes one of the predominant uses of cinnamon, and it has been used for the treatment of primary dysmenorrhoea, joint, and muscle pain since ancient times. In a controlled clinical trial, the delivery of two cinnamon capsules, each containing 420 mg of C. cassia bark powder, three times a day for two days, reduced the severity, duration, and systemic symptoms of primary dysmenorrhoea in comparison with placebo. Overall, the current clinical evidence is however insufficient to support the efficacy of cinnamon; further investigations are thus warranted [43][44][45].

5.3. Animal Studies

Cinnamon bark extracts from Cinnamomum species have anti-inflammatory, analgesic, and antioxidant properties. The anti-inflammatory activities of two constituents (cinnamic aldehyde and α-terpineol) from Cinnamomum cassia bark were evaluated in vivo and in vitro. The in vitro test assessed the capacity of C. cassia bark constituents to modulate secretion of inflammatory mediators using the LPS-stimulated RAW264.7 macrophage model. The in vivo anti-inflammatory activity was evaluated using carrageenan-induced hind-paw edema in mice. Raw extracts from C. cassia bark were examined for the same activities for comparison with the constituents [46].Both constituents and crude extract inhibited LPS-induced production of NO and secretion of TNF-α and IL-6 by murine macrophages. Cinnamic aldehyde dose-dependently reduced the expression of iNOS and COX-2 in vitro. It also suppressed phosphorylation of IκB-α and activation of NF-κB. In the in vivo model, cinnamic aldehyde significantly inhibited carrageenan-induced paw edema. The anti-inflammatory action was accompanied by suppression of iNOS and COX-2 expression in paw tissue, reduced NF-κB–DNA binding activity, and up-regulation of antioxidant enzymes (superoxide dismutase, catalase, and glutathione peroxidase) in the liver [47][48].

6. Analgesic Properties of Cinnamon

Cinnamon modulates chemical and behavioral responses of nociceptive sensory neurons, suggesting its potential to attenuate chronic pain. This well-known aromatic spice has been utilized extensively as a herbal medicine for various disorders associated with painful conditions. Cinnamon bark and its phytoconstituents offer a wide spectrum of pharmacological properties, including antioxidant, anti-inflammatory, and analgesic activities, which primarily target pathways involved in the molecular genesis of inflammation and pain. Supporting evidence from animal studies and clinical trials underlines the analgesic potential of cinnamon [49].

Historically, cinnamon was employed in numerous ancient cultures, including India, China, Egypt, Greece, and Rome. More recent assessments have demonstrated that essential oils extracted from both cinnamon bark and leaves exhibit significant analgesic activities. Highlighting phytochemical synergy, combinations of turmeric, ginger, and cinnamon are used for treating various inflammatory ailments, with their active components—curcumin, gingerol, and cinnamaldehyde—occupying distinct molecular sites involved in pain and inflammation signaling. These agents may also prevent acute peripheral inflammatory responses associated with experimental tooth movement. [50][51].

6.1. Pain Pathways Modulation

The analgesic properties of cinnamon have been frequently studied on animals. Cinnamon decreases prostaglandin synthesis and prostaglandin concentrations, which indicates its analgesic activity [51][52]. It can be used for joint pain, menstrual cramps, and muscle aches, as it also reduces the dilation of blood vessels and muscles. Cinnamon's action modulates several signaling pathways, including the mitogen-activated protein kinase (MAPK), the transient receptor potential (TRP) channels, and the prostaglandin E2 (PGE2) receptor pathway [53].

The analgesic effect of turmeric has been proven and confirmed in studies. Ginger modulates pain through several mechanisms influencing the attenuation of prostaglandin biosynthesis [54] the action on the 5-HT3 receptors, the vanilloid nociceptor, and the opioid system. The combination of turmeric or ginger with cinnamon produces a synergistic effect [55][56].

6.2. Traditional Uses

Cinnamon is a genus of evergreen trees and shrubs native to tropical and subtropical areas of Asia, the Indian subcontinent, and Australia, belonging to the Lauraceae family. Several species are traded as the spice cinnamon, of which Cinnamomum verum (Ceylon cinnamon or Cinnamomum zeylanicum) is considered true cinnamon and was historically the most highly prized kind [57].The bark is harvested primarily between July and October, stripped from the tree, and sun-dried, resulting in the familiar rolls known as cinnamon sticks or quills. Quills can also be processed into cinnamon oil, an essential oil obtained by the steam distillation of bark or leaves. The genus Cinnamomum contains around 250 species of evergreen trees and shrubs, classified in six sections (Alternecinnamon, Camphora, Cinnamomum, Cinnamodendron, and two sections of Ocotea) [58][59].

6.3. Recent Research Findings

Recent research has focused on the immunosuppressive effects of A-type procyanidin oligomers from Cinnamomum tamala, a species closely related to cinnamon. Immunosuppressive components in cinnamon bark extracts were identified by examining splenocyte proliferation induced by ConA or LPS. Among procyanidin oligomers, cinnamtannin D1 (CTD-1) significantly inhibited splenocyte proliferation, reduced cytokine levels of IFN-γ and IL-2, and suppressed delayed-type hypersensitivity responses. These findings indicate that procyanidin oligomers contribute to the immunosuppressive activities of cinnamon bark, highlighting CTD-1 as a potential therapeutic agent for immune-related diseases [1]. The antioxidant capacity of cinnamon has also been investigated in relation to palm oil stability. Ethanolic extracts of cinnamon, turmeric, and ginger exhibited antioxidant, antibacterial, and anti-inflammatory activities. Turmeric and ginger extracts were effective against all tested bacteria, with ginger showing the highest antioxidant potential in the FRAP test. Cinnamon extract demonstrated good antioxidant capacity, especially in water extracts, indicating strong activity [3]. Similarly, essential oils of cinnamon and clove exhibited the best antioxidant performance among tested oils, exhibiting high DPPH scavenging abilities and significant phenolic content. Cinnamon extracts displayed appreciable antioxidant capacities in various radical scavenging assays, supporting their use as natural antioxidants in food products. An evaluation of Indian spices confirmed cinnamon's antioxidant activity. Given that storage conditions of refined deodorized palm oil affect product quality and safety, these findings suggest potential applications of cinnamon extracts to improve palm oil stability [60][61].

7. Synergistic Effects with Other Herbal Remedies

The combined use of cinnamon with other herbal remedies, such as turmeric and ginger, exemplifies the enhanced therapeutic potential achievable through synergistic interactions [62]. Herbal combinations can be pharmacodynamically interconnected, as highlighted by the complementary properties of curcumin and cinnamaldehyde, representing the primary active constituents of turmeric and cinnamon, respectively. These compounds share similar therapeutic activities and demonstrate augmented effects when administered together. In the context of Covid-19, an Indian Ayurvedic formulation comprising turmeric, cinnamon, and ginger dispersed in sweet honey has been recognized for its potent inhibitory efficacy against angiotensin-converting enzyme 2 (ACE2), the cellular entry receptor for SARS-CoV-2 infection [63]. The incorporation of cinnamon into established remedies such as turmeric and ginger underscores its status as an important herbal medicine and highlights its diverse pharmacological properties [64].

7.1. Combination with Turmeric

Essential oils are employed globally in naturopathic medicine, homeopathy, and aromatherapy for their health benefits [65]. The essential oils of turmeric possess pharmacological activities and are utilized in traditional medicine as, for example, antimicrobial agents, an insect repellent, an antifungal, a food preservative, and an anticarcinogenic agent. Combination with turmeric was shown to enhance its therapeutic effects [66]

7.2. Combination with Ginger

Pharmacological evidence indicates the effective use of the turmeric corm, cinnamon bark, and ginger rhizome as a synergistic medicine for bronchitis, asthma, and pneumonia [67].Many studies have shown that ginger exhibits an analgesic effect. The modulation of pain pathways by the active compounds in these herbal products provides a helpful scientific basis for their traditional use. Analgesic activity has also been attributed to ginger. Cinnamon bark extract or its bioactive compounds, such as cinnamaldehyde, may contribute to analgesic activity, as demonstrated by a significant analgesic effect in the acetic acid-induced writhing test [68].

8. Safety and Toxicity of Cinnamon

A great number of food safety agencies have established an acceptable daily cinnamon intake. The U.S.A. Food and Drug Administration has viewed cinnamon as a generally recognized as safe (GRAS) product. The recommended daily allowance is 1.8 g, an intake not leading to adverse effects. The European Food Safety Authority concluded that exposure to coumarin, a natural component in cinnamon, should be no more than 0.1 mg per kilogram of body weight per day. Toxicological assessments concluded that consumption of up to 6 g cinnamon powder per day during six weeks was not associated with adverse effects. Overdose, however, resulted in respiratory distress, increased pulse rate and sweating, and a depressed immune system. Cinnamon intake is also associated with higher risk of oral cancer and amplification of rosacea symptoms [69]. Coumarin is hepatotoxic and may cause liver disease in individuals with pre-existing disorders. While aqueous and ethanolic extracts have shown no toxic effects in rat models, bioactive molecules such as trans-cinnamaldehyde and coumarins show toxicological profiles promoting liver damage, increased cancer risk, mouth sores, hypoglycemia, respiratory problems, and drug interactions [69]. Consequently, long-term administration of high doses or extracts requires toxicological evaluation. Within the human biological system, consumption of 0.1 mg coumarin per kg body weight is considered safe. The European Food Safety Authority designated the same daily NOAEL (No-Observed-Adverse-Effect-Level) for coumarin intake [70].External use of cinnamon essential oil can provoke adverse reactions including skin irritation and burning. Similar to other herbal remedies, cinnamon essential oil interacts with statins, antitumour and antifungal drugs, blood pressure medications, and also promotes significant decreases in blood sugar levels, demanding caution in diabetic patients. The use of cinnamon-based products is generally considered safe when quality control measures in cultivation, harvesting, processing, and storage of botanical sources are implemented. In these cases, purity, stability, toxicity, and standardization need to be properly assessed [71][72][73].

8.1. Recommended Dosages

Cinnamon bark is associated with minimal toxicity over a wide range of dosages in animals, suggesting potential for safe use in humans. For antioxidant efficacy, recommended intake levels in humans from earlier reviews suggest a range of 500 mg to 3 g per day [74]. Limited data also describe the safety profile of Cinnamomum verum bark, one of the main sources of cinnamon extracts. Immunosuppressive effects of procyanidin oligomers isolated from the related species Cinnamomum tamala inform the need for dosage considerations. Results indicate that procyanidin oligomers contribute to the immunosuppressive activity of cinnamon bark extracts [75]

8.2. Potential Side Effects

Although cinnamon bark is generally recognized as safe (GRAS) as a food additive, it may have harmful effects when taken in excessive amounts or combined with other drugs. Specific studies indicate that the methanolic extract of Cinnamomum zeylanicum increases serum glucose levels and decreases serum cholesterol levels in healthy albino rats fed a high-fat diet, while also exhibiting varying effects on platelet counts depending on the dosage and dietary composition [76]. Doses exceeding 1.7 g of cinnamon can cause mucosal lesions and later-stage liver damage. The bark contains coumarin, a compound with hemolytic and carcinogenic activities that can be toxic even after short-term consumption, particularly in individuals with impaired liver function, and thus its ingestion should be limited. Moreover, in vivo studies reveal that the aqueous extract of Cinnamomum zeylanicum reduces circulating myocardial damage markers such as lactate dehydrogenase and carcinoembryonic antigen, ameliorates blood pressure and heart rate in prehypertensive subjects, and decreases serum brain-derived neurotrophic factor in healthy volunteers [77][78].

9. Cinnamon in Traditional Medicine

Cinnamon ranks among the most widely used spices and represents one of the earliest medicines from an aromatic tree bark ever acquired by humans. Its bark has been studied abundantly for many properties, yet the antioxidant, anti-inflammatory, and analgesic properties of this valuable spice have not been reviewed in an integrated format [79].This article briefly revisits the botanical profiles of Cinnamomum verum and presents a new review of relevant scientific literature on the composition and content of polyphenols and essential oils in cinnamon bark that show evidence of antioxidant, anti-inflammatory, and analgesic potential. The paper introduces new approaches that compile information on polyphenols present in cinnamon bark with a review of cinnamon essential oils that explains their remarkable antioxidant and anti-inflammatory properties. Recent studies indicate a correlation between cinnamon ingestion and reduced inflammation. Cinnamon bark has also been utilized in traditional medicine to treat blood circulation disorders and inflammation. This spice is generally consumed as a dietary supplement alongside herbal extracts such as turmeric and ginger to mitigate cell damage caused by oxidative stress; in combined use, cinnamon and turmeric exhibit enhanced anti-inflammatory and antioxidant effects [80].

9.1. Historical Uses

The medicinal application of cinnamon bark dates to ~2800 BC, when the spice was used for embalming when blended with myrrh [79]. From this early point, the bark was used to treat ailments and conditions such as respiratory and digestive problems. As a reflection of this long history of use, the spice was one of the first to be imported into Europe [82]. In the medieval period, a mixture of the powder and honey (often combined with other herbal ingredients) was the standard remedy administered to the sick. There are many reports of the successful use of cinnamon bark, its extracts, and its bioactive compounds in treating several diseases and disorders. The efficacy of these interventions has been attributed to the antioxidant, anti-inflammatory, and analgesic properties of the bark; these have been demonstrated in numerous in vivo and in vitro studies. Hence, many of the traditional uses of cinnamon bark have been validated [83].

9.2. Cultural Significance

Cinnamon (Cinnamomum spp., family Lauraceae) has been an integral part of India’s ancient cultural beliefs, customs, and medicine for more than 4000 years. This fragrant spice traditionally has been used in Ayurvedic medicine to treat cold, indigestion, and other ailments, and it still is used today in over-the-counter medical preparations. Cinnamon’s recorded history extends back to when Ayodhya was the capital of Kosala . Sushruta Samhita (ten centuries prior to Christ) and the texts of Charaka (five centuries prior to Christ) prescribe cinnamon as a stimulant and tonic to treat bronchitis and catarrh. Cinnamon is more widely used in Indian and South Asian cultures than in Western cultures, where it generally is utilized only in culinary preparations due to differences in cultural attitudes, culinary traditions, and religious beliefs [7]. Because it was highly prized among ancient nations, including the Chinese, the Egyptians, the Greeks, and the Romans, cinnamon had considerable interface in cultural rituals and daily social life, agricultural traditions, and religious ceremonies [84].

10. Modern Applications of Cinnamon

Currently, cinnamon is extensively utilized in the formulation of dietary supplements and various pharmaceutical products. Given the widespread acceptance of dietary supplements as an alternative to conventional medicine for the treatment and management of diseases, cinnamon’s incorporation into these supplements represents a practical approach to harnessing its medicinal properties. Its multifaceted pharmacological effects ensure that it remains a cornerstone of medicinal plants widely used for health promotion worldwide. As such, cinnamon continues to be a crucial materia medica for countless individuals who rely on natural remedies for their healthcare needs [85].

10.1. Dietary Supplements

Dietary supplements, defined by the Council for Responsible Nutrition as products taken orally that contain dietary ingredients intended to supplement the diet, encompass vitamins, minerals, herbs or botanicals, amino acids, and various substances in concentrated forms such as tablets, capsules, softgels, gelcaps, powders, and liquids. Nutrients typically consumed in ample amounts are less common as supplements, with additional exceptions. Cinnamon bark, derived from the dried inner bark of Cinnamon trees, has been widely utilized in the food industry and in folk medicine since antiquity [1]. Contemporary analysis of cinnamon bark has led to the isolation of numerous compounds exhibiting antioxidant, anti-inflammatory, and analgesic properties, including procyanidin oligomers, essential oils, polyphenols, and flavonoids [85]. Due to its beneficial therapeutic profiles and wide accessibility, cinnamon bark has been extensively incorporated into clinical pharmaceutical preparations, food products, and dietary supplements. [36][25][83]

10.2. Pharmaceutical Innovations

Alongside its many uses in food and traditional day-to-day applications, cinnamon has also established itself as a worthy weapon alongside modern pharmacological remedies. Recently, researchers have begun exploring the possibility of using cinnamon as a natural phytomedicine, targeting pharmaceutical therapies based on the plant’s diverse phytochemical profile and acclaimed health benefits. The therapeutic value of cinnamon, either alone or in combination with other herbal remedies such as turmeric and ginger, has developed a strong platform for inclusion in dietary supplements as well as the inspiration for novel pharmaceutical products [33]. Implementations of this kind remain an open door for future research, especially given the importance of the clinical trials necessary for developing comprehensive and reliable health data to formulate safe guidelines [31]. Recent years have seen an exponential growth in the number of cinnamon-related studies and literature, with roughly eighty percent of the work published after 2010. This increase in research efforts reflects the broader global trend towards alternative pharmaceutical therapies—one that will almost certainly establish itself as a mainstream course of action within the next decade [84]

11. Future Research Directions

Deciphering the multitarget mechanism of Cinnamomum zeylanicum essential oil in inflammation highlights cinnamon as a multifunctional herbal medicine. Future research should further explore the anti-inflammatory, antioxidant, and antimicrobial activities of cinnamon and key compounds such as cinnamaldehyde and cinnamic aldehyde [85]. Investigating the molecular pathways involved—for example, TLR4/MyD88 signaling—can deepen understanding of their mechanisms. Structure–activity relationship studies may assist in discovering more potent derivatives for therapeutic applications. Furthermore, the vasodilatory effects via the nitric oxide–cGMP–PKG pathway and bioactive compounds like tuberosin constitute promising directions. The synthesis of ester derivatives from natural sources and their biological activities also merits attention. Clinical studies are needed to validate efficacy and safety profiles, particularly for inflammatory skin conditions such as rosacea and demodicosis. These avenues could contribute to the development of cinnamon-based therapeutics for inflammatory diseases, cancer, and vascular health [42].

Extracts from turmeric, ginger, and cinnamon are rich in antioxidant, antibacterial, and anti-inflammatory activities; turmeric and ginger ethanolic extracts proved effective against bacterial challenge, with ginger displaying the highest antioxidant potential [33]. Cinnamon extract holds good antioxidant activity; the water extract demonstrates the highest value. Essential oils from cinnamon and clove show strong antioxidant activity in DPPH scavenging assays. Cinnamon extracts exhibit radical scavenging capacities, representing alternatives to synthetic antioxidants in food products.

11.1. Emerging Trends

Copper has essential roles in all subcellular compartments, in non-ceruloplasmin cuproproteins, including involved in respiration (Complex IV Cox1/2), the antioxidant (superoxide dismutase 1, Sod1), the pigment and neurotransmitter (tyrosinase), and the amine oxidase (peptidylglycine alpha-amidating monooxygenase). Due to its higher reactivity relative to the other two metalloids, Mn and Fe, Cu homoeostasis is tightly regulated to maintain a balance between the foetal Cu overload and adult deficiency and by itself oxidative stress through Fenton chemistry. Cu cellular uptake is regulated by different importers, including the copper transporter (Ctr1) and Ctr2, which in mammals mediates the homoeostasis of either Cu(I) or Cu(II); Cu(I) is subsequently loaded to cuproproteins by copper chaperones (Atox-1, CCS, Cox-11). Because upregulation of non-ceruloplasmin Cu (NCC) is involved in neurodegenerative disorders, recently, many CCs have been suggested as novel potential candidate genes for such diseases [3]. Excessive NCC can lead to increased oxidative stress: this molecular mechanism could underlie the alteration in NCC metabolism since foetal life, which is active in schizophrenia and other neurodevelopmental diseases.

11.2. Potential Clinical Trials

Recent studies indicated several therapeutic properties of cinnamon, including potential anti-microbial, anti-parasitic, anti-oxidant, blood glucose lowering, and cardiovascular benefits; a phase I randomized, double-blinded, placebo-controlled, crossover clinical trial assessed these properties and safety in healthy adults [86]. Cinnamon and clove essential oils, with cinnamaldehyde as the major component in cinnamon (62.04%), were formulated into nanoemulsions with droplet sizes below 200 nm at room temperature to prevent vapor loss; both eugenol and cinnamaldehyde exhibited anti-inflammatory effects akin to COX inhibitors and the ability to inhibit inflammation and pain via peripheral mechanisms. Analgesic effects involved blockade of peripheral pain pathways without central influence (hot plate test). In the formalin test, cinnamon-NG affected the second phase of nociceptive response, indicating anti-inflammatory and anti-nociceptive activity. Rat paw licking tests demonstrated cinnamon-NG's inhibition of pain responses in both phases, implicating peripheral and central mechanisms, with effects comparable to other extracts; eugenol's anti-nociceptive effects predominantly target inflammatory pain peripherally, engaging opioid receptors [31]. Evaluation of ethanolic extracts of cinnamon, turmeric, and ginger highlighted considerable antioxidant, antibacterial, and anti-inflammatory activities; turmeric and ginger were effective against all tested bacteria, with ginger showing the highest antioxidant potential. Cinnamon extract displayed notable antioxidant capacity, particularly in water extracts. Essential oils analysis revealed that cinnamon and clove oils possessed the highest antioxidant activities, marked by significant DPPH scavenging and elevated phenolic content. Various spices, including cinnamon, exhibited appreciable antioxidant capacities across radical scavenging assays. Palm oil stability under different storage conditions benefited from the application of Ficus exasperata leaves [33].

12. Conclusion

Cinnamon, particularly its bark, is a potent source of bioactive compounds with significant antioxidant, anti-inflammatory, and analgesic properties. Extensive research on the phytochemical composition of cinnamon bark, which includes essential oils, polyphenols, and flavonoids, has demonstrated its capacity to mitigate oxidative stress, reduce inflammation, and alleviate pain. These beneficial properties make cinnamon an appealing candidate for therapeutic applications, particularly in the management of conditions related to oxidative damage, inflammation, and chronic pain.Cinnamon's bioactive constituents, such as cinnamaldehyde and cinnamic acid, play a pivotal role in these effects, acting through various mechanisms to modulate enzymatic activities, neutralize free radicals, and regulate inflammatory pathways. In both in vitro and in vivo studies, cinnamon has shown substantial evidence of antioxidant capabilities, including scavenging free radicals and influencing key biochemical pathways involved in inflammation. Furthermore, its analgesic effects are substantiated by its ability to modulate nociceptive pathways and reduce the severity of pain in animal models.Although cinnamon has a rich history in traditional medicine, modern clinical and animal studies support many of its therapeutic applications. Its combination with other herbs like turmeric and ginger further enhances its pharmacological potential, providing a broad spectrum of benefits for managing inflammation and pain. However, while cinnamon is generally recognized as safe, excessive consumption, particularly of compounds like coumarin, can lead to adverse effects such as liver toxicity, indicating the need for careful dosage management.Future research should continue to explore cinnamon's molecular mechanisms, safety profiles, and synergistic effects with other herbal remedies, paving the way for its broader inclusion in modern pharmacological therapies. As cinnamon's therapeutic potential unfolds, it holds promise not only as a dietary supplement but also as a valuable natural remedy for a range of chronic conditions, particularly those associated with inflammation, oxidative stress, and pain.

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