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# Cardamom (*Elettaria cardamomum* L.) as a functional medicinal spice: Phytochemical composition, pharmacological actions and antimicrobial potentials

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## Abstract

Cardamom (*Elettaria cardamomum* L.), one of the world's most valued spices, possesses a rich ethnomedicinal history and an exceptional phytochemical profile that underlies its extensive therapeutic and industrial potential. This review comprehensively examines the phytochemical composition, pharmacological properties, antimicrobial activities, safety profile and industrial applications of cardamom, while also identifying key research gaps and future opportunities. Cardamom's essential oil is dominated by monoterpenes such as 1,8-cineole, a-terpinyl acetate, linalool, limonene and sabinene, complemented by a diverse array of flavonoids, phenolic acids, tannins, saponins, sterols and micronutrients. Together, these compounds contribute to a wide spectrum of biological activities. The spice demonstrates robust antioxidant and anti-inflammatory effects through modulation of reactive oxygen species, enhancement of endogenous antioxidant enzymes and suppression of pro-inflammatory cytokines and COX/LOX pathways. Cardamom exhibits significant pharmacological actions, including antidiabetic activity via enhancement of insulin sensitivity and inhibition of carbohydrate-digesting enzymes, cardioprotective effects through vasodilation, lipid regulation and antithrombotic mechanisms and gastroprotective actions such as stimulation of digestive enzymes and mucosal protection. It also shows neuroprotective and anxiolytic effects attributed to modulation of neurotransmission and reduction of oxidative stress, alongside promising anticancer properties involving apoptosis induction, inhibition of tumor progression and suppression of oxidative DNA damage. Additionally, cardamom demonstrates broad antimicrobial potential against bacterial, fungal and select viral pathogens, with applications in natural food preservation and modulation of gut microbiota.Toxicological evidence indicates that cardamom is generally safe for human consumption, with negligible acute or chronic toxicity at culinary and therapeutic doses, although concentrated essential oils require cautious use. Its industrial applications span pharmaceuticals, nutraceuticals, functional foods, aromatherapy, perfumery and sustainable packaging technologies, supported by advancements in extraction and encapsulation methods. Despite these benefits, significant research gaps remain, particularly regarding clinical validation, standardization of extracts, advanced mechanistic studies and sustainable cultivation strategies. Addressing these gaps will enhance the evidence base and facilitate the integration of cardamom-derived products into modern health systems. Overall, cardamom emerges as a versatile medicinal spice with substantial promise for therapeutic, industrial and nutraceutical innovations.

## 1. Introduction

Spices have occupied a central place in human civilization for thousands of years, not only as flavoring and aromatic agents but also as invaluable medicinal resources. Among the diverse spices that enrich global culinary and healing traditions, cardamom (*Elettaria cardamomum* L.) stands out as one of the most esteemed and biologically significant. Often celebrated as the "Queen of Spices," cardamom has been treasured since ancient times for its pleasant aroma, warm flavor and therapeutic virtues. From the ancient trade routes of the Indian subcontinent to contemporary global markets, the demand for cardamom has persisted due to its multifaceted applications in food, medicine, perfumery and cultural customs. In modern scientific discourse, cardamom is increasingly recognized as a functional medicinal spice with a remarkable composition of phytochemicals, diverse pharmacological effects and broad-spectrum antimicrobial properties. These characteristics position cardamom as an emerging candidate for the development of natural therapeutics, nutraceuticals and functional foods. Cardamom belongs to the family Zingiberaceae, which includes several medicinally important species such as ginger and turmeric. The genus *Elettaria* is native to the evergreen forests of the Western Ghats of South Indiaa recognized

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biodiversity hotspotand has now spread to other tropical regions including Sri Lanka, Guatemala and Tanzania. Although, historically cultivated primarily for culinary purposes, cardamom has been deeply embedded in traditional medical systems such as Ayurveda, Unani and Siddha. Classical texts describe its use in soothing gastrointestinal disorders, enhancing respiratory health, refreshing breath and balancing the body's humoral systems (Ashokkumar *et al*., 2020). Over centuries, empirical knowledge surrounding cardamom's medicinal significance has accumulated across cultures, yet only in recent decades has scientific research begun to unravel the molecular and biochemical foundations of its therapeutic potential.

The medicinal value of cardamom is largely attributed to its exceptional spectrum of phytochemicals, particularly the essential oils that makeup 2-10% of the dried capsules. These essential oils are rich in monoterpenes, sesquiterpenes, flavonoids, phenolic acids, sterols and numerous minor constituents that exert synergistic bioactivity. Key molecules such as $\alpha$-terpinyl acetate, 1,8-cineole (eucalyptol), linalool, limonene and sabinene have been documented for their pharmacological importance. The complexity of the phytochemical matrix not only contributes to cardamom's characteristic aroma and flavor but also confers diverse biological functions, ranging from antioxidant and anti-inflammatory effects to metabolic regulation and antimicrobial activity. Ongoing advancements in analytical chemistry, including gas chromatography-mass spectrometry (GC-MS), high-performance liquid chromatography (HPLC) and nuclear magnetic resonance (NMR), have allowed researchers to characterize these compounds more accurately and evaluate their biochemical interactions in biological systems.In the broader landscape of phytomedicine, cardamom holds relevance for several reasons (Yahyazadeh *et al*., 2021). Firstly, the global interest in natural remedies and plant-derived therapeutics has increased dramatically, driven by consumer preference for clean-label products, concerns about synthetic drug toxicity and growing evidence supporting the benefits of phytochemicals in disease prevention. Spices, by virtue of their daily consumption and high antioxidant and antimicrobial potential, are gaining recognition as functional foods capable of supporting metabolic and immune health. Cardamom, in particular, stands out because its bioactive constituents are highly bioavailable and possess multi-targeted mechanisms of action, making them suitable for addressing complex health conditions such as inflammation, oxidative stress, metabolic disorders and microbial infections.

Furthermore, the emergence of chronic lifestyle disorders has intensified scientific exploration into natural therapeutics capable of modulating metabolic pathways and minimizing oxidative damage. Cardamom has shown promising effects in reducing blood pressure, improving lipid metabolism, enhancing glucose homeostasis and mitigating oxidative stress at the cellular level. Its pharmacological actions have been associated with modulation of inflammatory mediators, scavenging of free radicals and enhancement of endogenous antioxidant enzymes. Additionally, cardamom's influence on gastrointestinal healthone of its oldest documented useshas been substantiated by scientific studies showing its ability to stimulate digestive enzymes, improve gut motility and protect gastric mucosa. These emerging insights offer a scientific basis for integrating cardamom into dietary and therapeutic strategies aimed at promoting digestive and metabolic well-being. Another compelling dimension of cardamom's bioactivity is its potent antimicrobial potential. In an era where antimicrobial resistance has become a global crisis, the search for safe and effective natural antimicrobials has intensified. Cardamom essential oil contains compounds that exhibit strong inhibitory effects against a broad range of pathogenic bacteria, fungi and even select viruses. Its antimicrobial action is believed to involve disruption of microbial cell membranes, interference with enzyme activity, inhibition of biofilm formation and modulation of quorum sensing pathways. Studies have demonstrated its effectiveness against several clinically relevant pathogens, including *Escherichia coli*, *Staphylococcus aureus*, *Salmonella* spp., *Candida albicans* and *Aspergillus niger* (Garza *et al*., 2021). These findings underscore cardamom's potential as a natural preservative in the food industry and as a complementary agent in antimicrobial therapies.

Cardamom's therapeutic potential is further enhanced by its safety profile. Traditionally, cardamom has been consumed across cultures without adverse effects and toxicological evaluations have generally confirmed its safety at culinary and medicinal doses. Nevertheless, as interest grows in the use of concentrated extracts, essential oils and nano-formulated bioactives, understanding their safety, metabolism and long-term effects becomes essential. Scientific inquiries into toxicity thresholds, drug-herb interactions and pharmacokinetics will be critical for ensuring the safe and effective use of cardamom-based therapeutics. From an economic and social perspective, the cultivation and production of cardamom also hold substantial importance. Regions such as India and Guatemala are major producers and cardamom farming supports the livelihoods of thousands of smallholder farmers. The spice's economic value and global demand have encouraged research into improving cultivation practices, post-harvest processing and genetic improvement to enhance yield and quality. Environmental factors, including altitude, soil type, temperature and shade levels, play key roles in determining the essential oil content and phytochemical profile of cardamom. Understanding these influences is crucial for standardizing quality and developing value-added products tailored to pharmaceutical and nutraceutical applications. Despite its rich history and multifaceted applications, cardamom remains underexplored compared to other medicinally important spices such as turmeric and cinnamon. Although numerous studies have examined individual components of cardamom's phytochemistry and pharmacology, comprehensive and integrative reviews that combine phytochemical insights with pharmacological and antimicrobial perspectives are relatively limited. A holistic understanding of cardamom's functional properties is essential for advancing its use in evidence-based medicine, functional food development and therapeutic innovations. By synthesizing current knowledge on its chemical composition, biological activities and mechanisms of action, researchers can identify knowledge gaps and opportunities for future investigation. This review aims to provide a comprehensive and updated synthesis of the phytochemical composition, pharmacological activities and antimicrobial potentials of cardamom. By integrating traditional knowledge with modern scientific evidence, the review emphasizes the multifaceted therapeutic value of cardamom and its emerging relevance in natural medicine. Special attention is given to its essential oil constituents, non-volatile phytochemicals, antioxidant activity, anti-inflammatory mechanisms, metabolic effects, cardiovascular benefits, digestive health support, anticancer potential, neuroprotective properties and antimicrobial mechanisms. The review also highlights current gaps in research, including the need for clinical trials, standardization protocols, deeper mechanistic studies and safety evaluations.

## 2. Botanical description and taxonomy

Cardamom (*E. cardamomum*) is a perennial, herbaceous spice crop belonging to the family Zingiberaceae, the same botanical family that includes ginger and turmeric. Renowned for its aromatic seeds and distinctive essential oil profile, cardamom is cultivated widely across tropical regions and holds immense commercial and medicinal value. Its botanical characteristics, cultivation ecology, varietal differences and environmental influences significantly shape its phytochemical composition and essential oil yield. A detailed understanding of these botanical and agronomic aspects is crucial for improving crop quality and optimizing the therapeutic potential of its bioactive constituents. Cardamom's botanical identity is well-established within the monocotyledonous order Zingiberales, belonging to the family Zingiberaceae, which includes several economically important aromatic and medicinal plants. Taxonomically, it is classified under the kingdom *Plantae*, clade Angiosperms, clade Monocots, order Zingiberales, family Zingiberaceae, genus *Elettaria*, with the species recognized as *E. cardamomum*. In addition to these botanical varieties, numerous region specific cultivars have evolved in major cardamom-producing regions such as India, Sri Lanka and Guatemala, each exhibiting unique morphological features, flavor profiles and essential oil compositions shaped by local environmental conditions and long-term cultivation practices.

## 3. Phytochemical composition

### 3.1 Essential oil constituents

Cardamom essential oil represents the most characteristic and biologically active component of the spice, contributing 2-10% of the dry capsule weight. This volatile fraction is dominated by monoterpenes and their oxygenated derivatives, which collectively shape the spice's aroma, flavor and therapeutic value. Major compounds include 1,8-cineole, a monoterpene oxide responsible for the cool, eucalyptus-like aroma and known for its bronchodilatory, anti-inflammatory and antimicrobial activities; á-terpinyl acetate, the principal ester imparting the sweet, fruity fragrance typical of high-quality cardamom; linalool, a floral-scented alcohol with anxiolytic and anti-inflammatory effects; limonene, a citrus-like monoterpene associated with antioxidant and gastroprotective properties; and sabinene, a spicy, woody hydrocarbon noted for its antimicrobial potential. Although, present in smaller quantities, compounds such as geraniol, myrcene, β-pinene, nerolidol and borneol add complexity to the essential oil profile and often act synergistically to enhance therapeutic actions.The composition of these volatile oils varies significantly due to genetic, environmental, developmental and methodological factors. Genotypic differences among cultivars, such as the Malabar, Mysore and Vazhukka types, determine the relative proportions of key terpenoids, with Malabar varieties typically rich in α-terpinyl acetate and Mysore types exhibiting higher levels of 1,8-cineole. Environmental influences, including altitude, soil fertility, rainfall distribution, shade level and microclimatic conditions, further affect terpenoid biosynthesis (Verma *et al*., 2009). For example, high-altitude cardamom generally contains greater concentrations of oxygenated monoterpenes, contributing to superior aroma quality. Similarly, the stage of harvest plays a critical role, as essential oil content and composition peak at specific fruit maturity stages. Extraction techniques also significantly influence the chemical fingerprint. Conventional methods such as steam distillation and hydrodistillation often produce oils rich in 1,8-cineole but may degrade heat sensitive compounds, whereas advanced methods like supercritical $CO_2$ extraction and microwave assisted extraction yield higher-quality oils with better preservation of delicate esters and improved extraction efficiency. These factors collectively contribute to the chemical variability that defines the sensory and medicinal characteristics of cardamom essential oil.

### 3.2 Non-volatile phytochemicals

In addition to its volatile oil, cardamom contains a substantial array of non-volatile phytochemicals that contribute to its therapeutic and nutritional significance. Among these, phenolic compounds play a central role, encompassing both flavonoids and phenolic acids. Flavonoids such as quercetin, kaempferol, catechin and their glycosides are abundant and impart strong antioxidant, anti-inflammatory, cardioprotective and chemopreventive properties. Phenolic acidssuch as gallic, caffeic, ferulic and chlorogenic acids further enhance the antioxidant capacity, helping neutralize free radicals and modulate oxidative stress pathways. Together, these compounds form the biochemical basis of cardamom's traditional use in digestive, cardiovascular and metabolic health.

Other non-volatile constituents include tannins, saponins, alkaloids and glycosides, each contributing distinct bioactivities. Tannins impart astringency and exhibit strong antimicrobial and anti-inflammatory properties, supporting gastrointestinal protection. Saponins demonstrate cholesterol-lowering, immunomodulatory and antidiabetic effects, while alkaloids although present in smaller amountsmay contribute to the spice's digestive stimulant properties. Additionally, the seeds contain fixed oils comprising oleic, linoleic and palmitic acids, which support cardiometabolic function. Plant sterols such as β-sitosterol offer lipid-lowering and anti-inflammatory benefits. Cardamom is also a source of essential micronutrients, including vitamins (such as vitamin C and B-complex varieties) and minerals like potassium, calcium, magnesium and phosphorus (Souissi *et al*., 2020). The interplay of these non-volatile constituents with volatile terpenoids results in synergistic pharmacological effects, explaining the broad therapeutic potential of cardamom documented in traditional medicine and modern pharmacological studies.

### 3.3 Analytical techniques for chemical profiling

The rich and complex phytochemical composition of cardamom requires advanced analytical techniques for accurate identification, quantification and quality assessment. Gas chromatography mass spectrometry (GC-MS) is the most widely used technique for profiling volatile oils, enabling the detection of monoterpenes, sesquiterpenes and their oxygenated derivatives with high precision. For non-volatile compounds such as phenolics and flavonoids, high-performance liquid chromatography (HPLC) remains the method of choice due to its sensitivity and suitability for thermolabile molecules. More sophisticated methods like liquid chromatography-tandem mass spectrometry (LC-MS/MS) offer enhanced sensitivity and structural resolution, making them invaluable for elucidating complex phytochemical profiles and identifying trace metabolites.

Complementary spectroscopic techniques provide further insights into the chemical nature of cardamom. Fourier-transform infrared spectroscopy (FTIR) is used for rapid chemical fingerprinting and quality control, helping detect adulteration or compositional shifts. Nuclear magnetic resonance (NMR) spectroscopy plays a crucial role in structural elucidation of unknown compounds and is essential in authentication studies. UV-Visible spectrophotometry (UV-Vis) supports quantitative estimation of total phenolic content, flavonoids and other chromophoric compounds through standardized colorimetric assays. In recent years, chemometric tools such as principal component analysis (PCA), partial least squares discriminant analysis (PLS-DA) and hierarchical clustering have become increasingly important in interpreting complex analytical data. They assist in distinguishing between cultivars, identifying geographic origins and establishing quality benchmarks essential for both scientific research and commercial applications (Alam *et al.*, 2021). Despite these advancements, standardization challenges remain significant due to natural variability in cardamom's phytochemical composition. Influences such as geographical origin, genetic diversity, harvest maturity, extraction methods and storage conditions contribute to inconsistencies in chemical profiles. Establishing universally accepted reference standards for key compounds, refining analytical protocols and developing reliable quality markers are ongoing priorities in ensuring the purity, consistency and therapeutic efficacy of cardamom products used in the food, pharmaceutical and nutraceutical industries.

## 4. Pharmacological actions

### 4.1 Antioxidant activity

Cardamom exhibits a remarkable antioxidant potential due to its complex phytochemical composition, which includes monoterpenes (such as 1,8-cineole, α-terpinyl acetate and limonene), flavonoids (quercetin, kaempferol and catechin), phenolic acids and tannins. These constituents work synergistically to neutralize reactive oxygen species (ROS), reduce oxidative stress and prevent lipid peroxidation biological processes implicated in ageing and the pathogenesis of several chronic diseases. The antioxidant mechanisms of cardamom operate on multiple molecular levels. First, many of its compounds possess intrinsic free-radical scavenging abilities, enabling them to donate hydrogen atoms or electrons to destabilize highly reactive oxygen and nitrogen species (Bhat *et al.*, 2015). This prevents oxidative damage to cellular macromolecules such as lipids, proteins and DNA. Studies have demonstrated that cardamom extracts significantly inhibit lipid peroxidation in biological membranes, particularly in liver and cardiac tissues, thus offering protection against oxidative deterioration induced by toxins, stress and metabolic dysregulation.

In addition to direct ROS neutralization, cardamom enhances the body's endogenous antioxidant defense system. Several bioactive constituents upregulate antioxidant enzymes including superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx) and increase levels of reduced glutathione (GSH), a major intracellular antioxidant. This modulatory effect contributes to maintaining redox homeostasis and strengthens cellular resilience under oxidative pressure. Mechanistically, some terpenoids and phenolics in cardamom activate transcription factors such as Nrf2, which regulate antioxidant response element (ARE) mediated gene expression. Activation of this pathway leads to the transcription of genes encoding detoxifying enzymes and cytoprotective proteins. The ability of cardamom to modulate both enzymatic and non-enzymatic antioxidant systems suggests a dual protective mechanism, making it a promising natural agent for combating oxidative stress. Furthermore, antioxidant activity plays a foundational role in cardamom's broader pharmacological significance. Oxidative stress is a major contributing factor in chronic inflammation, metabolic disorders, cardiovascular diseases, neurodegeneration and cancer. By effectively reducing oxidative burden, cardamom mitigates many upstream triggers that lead to these conditions. For example, inhibiting lipid peroxidation not only preserves cellular membrane integrity but also prevents the formation of toxic lipid peroxidation byproducts such as malondialdehyde (MDA) and 4-hydroxynonenal (4-HNE). These metabolites can initiate inflammatory responses and cause mutagenic damage if not controlled. Therefore, the antioxidant profile of cardamom forms the biochemical basis for many of its therapeutic actions, linking its traditional medicinal uses with modern scientific understanding (Savan *et al.*, 2013).

### 4.2 Anti-inflammatory properties

Inflammation is a biological defense mechanism, but chronic or dysregulated inflammation is associated with multiple diseases including arthritis, diabetes, cardiovascular disorders and gastrointestinal diseases. Cardamom possesses significant anti-inflammatory properties owing to its rich polyphenolic content, essential oil constituents and various bioactive metabolites that modulate inflammatory pathways at both cellular and molecular levels. Key terpenoids such as 1,8-cineole, linalool and limonene are known to suppress pro-inflammatory cytokine production, while flavonoids like quercetin and kaempferol inhibit inflammatory signaling cascades.One of the primary mechanisms underlying cardamom's anti-inflammatory action is its ability to modulate the synthesis and release of major pro-inflammatory cytokines, including tumor necrosis factor-alpha (TNF-α), interleukin-1 beta (IL-1β) and interleukin-6 (IL-6). These cytokines play central roles in initiating and sustaining inflammation and are commonly elevated in inflammatory and autoimmune disorders. Studies have demonstrated that cardamom extracts and essential oils can significantly downregulate the gene expression and secretion of these cytokines in macrophages and other immune cells, thereby reducing systemic inflammatory responses. In addition to cytokine inhibition, cardamom is known to suppress the activity of cyclooxygenase (COX) and lipoxygenase (LOX) enzymes, which are responsible for the biosynthesis of pro-inflammatory prostaglandins and leukotrienes (El-Malti*et al.*, 2007). By inhibiting COX-2, in particular, cardamom reduces the production of prostaglandin E, (PGE), a mediator linked to inflammation, fever and pain. Similarly, inhibition of the LOX pathway prevents leukotriene formation, further contributing to anti-inflammatory effects. These dual inhibitory actions resemble the mechanism of some non-steroidal anti-inflammatory drugs (NSAIDs), although cardamom lacks many of the adverse side effects associated with synthetic drugs.

Beyond enzymatic pathways, cardamom influences intracellular signaling cascades that regulate inflammation. Many cardamom constituents modulate the NF-κB pathway, a central transcription factor involved in immune responses and inflammation. Oxidative stress often triggers NF-κB activation, leading to increased expression of inflammatory mediators. Cardamom's antioxidant activity attenuates this pathway, resulting in lower NF-κB activation and reduced inflammatory gene expression. Furthermore, some studies suggest that cardamom may modulate mitogen-activated protein kinase (MAPK) pathways, adding another dimension to its anti-inflammatory mechanisms. The cumulative effect of these molecular interactions makes cardamom beneficial in preventing and managing chronic inflammatory disorders. It has shown promising results in models of arthritis, colitis, metabolic inflammation and airway inflammation. Its natural anti-inflammatory components suggest potential therapeutic applications in functional foods, nutraceutical formulations and adjunctive therapies for chronic inflammatory diseases.

### 4.3 Antidiabetic and metabolic effects

Cardamom demonstrates significant antidiabetic and metabolic regulatory effects, making it a promising natural intervention for metabolic syndrome, type 2 diabetes mellitus (T2DM), obesity and related disorders. These benefits arise from a combination of phytochemicals that modulate glucose metabolism, lipid balance, insulin sensitivity, oxidative stress and digestive enzyme activity. One important mechanism involves cardamom's ability to improve glucose homeostasis through enhanced insulin sensitivity. Studies have shown that cardamom supplementation reduces fasting blood glucose, improves glucose tolerance and enhances insulin responsiveness, partly by modulating signaling pathways involved in glucose uptake. Key phytochemicals may activate glucose transporter proteins (such as GLUT4) in peripheral tissues, facilitating better glucose disposal. Another central mechanism in cardamom's antidiabetic action is its inhibitory effect on α-amylase and α-glucosidase, two important digestive enzymes responsible for carbohydrate breakdown in the gastrointestinal tract. By slowing down carbohydrate digestion and reducing postprandial glucose spikes, cardamom acts similarly to certain antidiabetic medications such as acarbose (Moulai-Hacene *et al*., 2020). This enzyme inhibition results from the binding of polyphenolic compounds to active sites, limiting substrate accessibility and reducing glucose liberation from complex carbohydrates.

Cardamom also exerts beneficial effects on lipid metabolism, making it valuable in managing dyslipidemia and metabolic syndrome. Regular intake of cardamom has been associated with reductions in total cholesterol, low-density lipoprotein cholesterol (LDL-C), triglycerides and an increase in high-density lipoprotein cholesterol (HDL-C). The lipid-lowering effect is largely attributed to compounds such as limonene, linalool and sitosterol, which modulate hepatic lipid synthesis, promote fatty acid oxidation and inhibit lipid peroxidation. Additionally, the antioxidant properties of cardamom help protect pancreatic β-cells from oxidative stressa major contributor to insulin resistance and β-cell dysfunction in diabetes. Cardamom's influence on metabolic inflammation adds further value to its antidiabetic potential. Chronic low-grade inflammation is a hallmark of metabolic syndrome and cardamom's anti-inflammatory properties reduce circulating inflammatory markers, thereby improving metabolic function. Moreover, cardamom contains compounds that may modulate adipokine secretion and promote healthier adipose tissue remodeling, contributing to improved weight regulation and reduced visceral fat accumulation (Castillo *et al*., 2023). Some studies have even suggested that cardamom may help regulate appetite and energy expenditure due to its thermogenic and digestive-enhancing properties.

### 4.4 Cardioprotective and hypotensive effects

Cardamom exhibits significant cardioprotective and antihypertensive properties, which are attributed to its diverse phytochemical profile, including monoterpenes such as 1,8-cineole, limonene, α-terpinyl acetate and various flavonoids and minerals. Cardiovascular diseases (CVDs) are often associated with oxidative stress, hyperlipidemia, inflammation and endothelial dysfunction and cardamom's multifaceted bioactive constituents act on several of these underlying mechanisms. One of the primary cardioprotective mechanisms involves vasodilation, which helps reduce systemic vascular resistance and subsequently lowers blood pressure. Several compounds in cardamom possess calcium channel-blocking activity, relaxing vascular smooth muscle and promoting improved blood flow. Additionally, the essential oil components have been shown to modulate nitric oxide (NO) pathways, enhancing endothelial derived relaxation and supporting normal vascular function. Cardamom's antihypertensive effects are also linked to its diuretic properties, which facilitate sodium excretion and contribute to improved blood pressure regulation (Alam *et al*., 2019). In human studies, regular consumption of cardamom powder has significantly reduced systolic and diastolic blood pressure, enhanced fibrinolytic activity and improved antioxidant status. These changes collectively support cardiovascular health and reduce the risk of hypertension-related complications. The lipid-lowering effects of cardamom further substantiate its cardioprotective potential. Flavonoids, sterols (such as β-sitosterol) and terpenes in cardamom inhibit cholesterol absorption, promote hepatic fatty acid oxidation and reduce oxidative modification of LDL particlesan important step in the formation of atherosclerotic plaques.

Moreover, cardamom exhibits antithrombotic potential, reducing platelet aggregation and preventing thrombus formationactivities essential for minimizing the risk of stroke and myocardial infarction. The antioxidant and anti-inflammatory properties of cardamom support cardiovascular protection by attenuating oxidative stress and inflammation within blood vessels, thereby improving endothelial function. Cardamom also mitigates lipid peroxidation, an important factor in the onset and progression of atherosclerosis. Reduction in markers such as malondialdehyde (MDA) and C-reactive protein (CRP) in response to cardamom supplementation further confirms its capacity to protect cardiac tissues.Taken together, cardamom's cardioprotective actions result from a combination of vasodilatory, lipid regulatory, antithrombotic, antioxidant and anti-inflammatory effects (Bano *et al*., 2016). This multifactorial activity reinforces its potential as a natural cardiovascular health-promoting agent, complementing conventional therapies and contributing to overall cardiometabolic well being.

### 4.5 Gastroprotective and digestive health benefits

Cardamom has a long history of traditional use as a digestive aid and gastroprotective remedy and modern research supports its beneficial effects on various aspects of gastrointestinal function. The digestive-enhancing properties of cardamom are attributed to its volatile oils, flavonoids, tannins and other bioactive constituents that collectively stimulate the secretion of digestive enzymes, enhance motility and support mucosal protection. Essential oil components such as 1,8-cineole, limonene and linalool act as carminativesagents that relieve gas, bloating and abdominal discomfortby relaxing gastrointestinal smooth muscles and reducing spasms. These effects make cardamom particularly useful in managing conditions such as dyspepsia, flatulence, indigestion and nausea. Cardamom also demonstrates notable antiulcer activity, protecting the stomach lining from damage induced by alcohol, NSAIDs, stress and other ulcerogenic substances. This protective effect is mediated by both antioxidant and anti-inflammatory mechanisms. By neutralizing ROS and inhibiting lipid peroxidation, cardamom reduces oxidative injury to gastric mucosa (Kandikattu *et al*., 2017). Additionally, its phytochemicals modulate inflammatory pathways by reducing levels of cytokines and inhibiting enzymes such as COX and LOX, thereby decreasing inflammation and promoting healing of gastric tissues. Some studies suggest that cardamom may enhance mucin secretion, which strengthens the protective mucosal barrier and prevents the penetration of harmful substances.

Furthermore, cardamom exhibits mild antimicrobial activity against several gastrointestinal pathogens, including *Helicobacter pylori*, a major contributor to gastritis, ulcers and gastric cancer. By inhibiting microbial growth and adherence to the gastric epithelium, cardamom contributes to maintaining a healthier gastrointestinal environment. Its digestive benefits extend to improving bile flow and supporting liver function, thereby aiding in fat digestion and detoxification. Cardamom also has a positive influence on gut motility, helping regulate bowel movements and alleviating constipation without causing dependence or irritation. Additionally, traditional medicinal systems such as Ayurveda classify cardamom as a *deepana-pacana* herb, meaning that it enhances digestive fire and improves nutrient absorption (Pavarino *et al*., 2023). Modern interpretations of this concept suggest that cardamom may modulate digestive enzymes, stimulate gastric secretions and support a balanced gut microbiota. Studies have also shown that cardamom can reduce symptoms of nausea and vomiting, making it useful during pregnancy (in moderation), travel, or digestive infections.

### 4.6 Anticancer properties

Cardamom exhibits promising anticancer properties, supported by a growing body of *in vitro* and *in vivo* studies that highlight its ability to inhibit carcinogenesis through multiple molecular pathways. The anticancer effects of cardamom arise from its rich phytochemical matrix, including monoterpenes (1,8-cineole, limonene, á-terpinyl acetate), flavonoids (quercetin, kaempferol) and phenolic acids, which possess potent antioxidant, anti-inflammatory and antiproliferative activities. Oxidative stress and chronic inflammation are widely recognized as key drivers of carcinogenesis, promoting DNA damage, mutation andtumor progression. By reducing ROS levels and suppressing inflammatory mediators, cardamom disrupts early carcinogenic events, making it a valuable chemopreventive agent. Cardamom's anticancer mechanisms include induction of apoptosis, inhibition of cell proliferation, modulation of carcinogen-metabolizing enzymes and suppression of tumor-promoting signaling pathways. Several studies have shown that cardamom extracts induce apoptosis in cancer cells by activating intrinsic and extrinsic pathways, involving caspase activation, mitochondrial membrane potential disruption and increased pro-apoptotic proteins (such as Bax) alongside decreased antiapoptotic proteins (such as Bcl-2) (Azgomi *et al*., 2024). In addition to promoting programmed cell death, cardamom inhibits cell cycle progression by modulating cyclins and cyclin-dependent kinases, thereby halting cancer cell proliferation.

Monoterpenes such as 1,8-cineole and limonene have also been shown to suppress tumor growth by regulating ROS-mediated signaling. In cancer cells, controlled increases in ROS levels can trigger apoptosis and cardamom appears to modulate this balance effectively. Additionally, cardamom influences detoxification pathways by enhancing phase II enzymes such as glutathione-S-transferase (GST), which help neutralize carcinogens. This detoxification mechanism plays a vital role in preventing the initiation of chemically induced cancers.Studies using animal models provide further support for the anticancer potential of cardamom. For example, cardamom supplementation has been shown to reduce the incidence and multiplicity of skin, gastric and colon tumors induced by chemical carcinogens. These effects are associated with reduced oxidative stress, suppressed inflammatory pathways and enhanced DNA repair responses. Cardamom also inhibits angiogenesisthe formation of new blood vessels that tumors require for growth and metastasisby downregulating pro-angiogenic factors.In addition to direct anticancer effects, cardamom's influence on metabolic function, immunity and detoxification indirectly contributes to cancer prevention (Mohemmad*et al*., 2024). Its modulatory role on gut microbiota may also play emerging roles in colorectal cancer prevention. While more clinical studies are required, current evidence strongly suggests that cardamom is a promising natural candidate for cancer prevention and complementary therapy, acting through a combination of antioxidant, anti-inflammatory and cytotoxic mechanisms.

### 4.7 Neuroprotective and anxiolytic effects

Cardamom has demonstrated noteworthy neuroprotective and anxiolytic properties, enabling it to modulate several neurological pathways involved in cognition, mood regulation, stress response and neurodegeneration. These activities arise from the combined contributions of phenolic compounds, flavonoids, essential oil constituents and micronutrients that work synergistically to protect neuronal cells and support optimal brain function. Several bioactive moleculesparticularly linalool, 1,8-cineole, limonene and quercetin exhibit the ability to cross the blood brain barrier and interact with neural circuitry, influencing both neurotransmitter systems and oxidative-inflammation pathways that play central roles in neurological health. One of the most important neuroprotective mechanisms of cardamom is its capacity to attenuate oxidative stress within the central nervous system. The brain is highly susceptible to oxidative damage due to its elevated oxygen consumption, abundant lipid content and limited antioxidant defenses. Cardamom's potent antioxidant constituents help scavenge free radicals, inhibit lipid peroxidation in neuronal membranes and enhance endogenous antioxidant enzymes such as superoxide dismutase and catalase (Younus *et al*., 2023). This protective effect reduces neuronal apoptosis, preserves synaptic integrity and minimizes the progression of neurodegenerative conditions such as Alzheimer's and Parkinson's diseases. Furthermore, cardamom's anti-inflammatory properties complement its antioxidant effects by suppressing microglial activation and reducing levels of pro-inflammatory cytokines, which are linked to neuroinflammation and cognitive decline. Cardamom also plays a significant role in modulating neurotransmitter systems, particularly those associated with mood, anxiety and stress regulation. Essential oil constituents such as linalool are known to enhance gamma-aminobutyric acid (GABA) signalingan inhibitory neurotransmitter pathway essential for reducing neural excitability and promoting relaxation. By modulating GABAergic pathways, cardamom produces anxiolytic effects similar to mild sedatives but without associated side effects. Additionally, compounds in cardamom may influence serotonin and dopamine pathways, contributing to improved mood, reduced stress perception and enhanced emotional balance. These actions support traditional uses of cardamom as a calming agent and align with modern evidence showing its ability to reduce anxiety like behaviors in animal models.

Moreover, cardamom's neuroprotective benefits extend to cognitive enhancement. Flavonoids like kaempferol and quercetin have been shown to support synaptic plasticity, enhance acetylcholine levels and improve spatial learning and memory. By improving cerebral blood flow and reducing oxidative damage, cardamom creates a favorable environment for neural functioning and cognitive performance. Its anxiolytic and stress reducing properties further support cognitive health by minimizing the detrimental effects of chronic stress on hippocampal neurons. Overall, cardamom exhibits multifaceted neuroprotective actions through oxidative stress reduction, anti-inflammatory effects, neurotransmitter modulation and cognitive support (Aziz *et al*., 2024). These combined mechanisms underline its potential as a natural therapeutic agent for managing anxiety, stress related disorders, mild cognitive impairment and neurodegenerative diseases. While further clinical research is warranted, current evidence highlights cardamom's promising role in neurological health.

### 4.8 Other pharmacological activities

Beyond its antioxidant, anti-inflammatory, cardioprotective, antidiabetic, digestive and anticancer actions, cardamom exhibits several additional pharmacological activities that further demonstrate its therapeutic versatility. Among these, hepatoprotective effects are especially well documented. Liver injury induced by toxins, alcohol, medications and metabolic stress often involves oxidative damage and inflammation pathways cardamom effectively modulates. Studies have shown that cardamom supplementation can reduce hepatic lipid peroxidation, restore antioxidant enzyme levels and improve liver function markers such as ALT, AST and ALP. These benefits can be attributed to cardamom's rich phenolic content and essential oil constituents that protect hepatocytes and promote detoxification pathways. Cardamom also demonstrates nephroprotective properties, offering protection against kidney damage caused by oxidative stress, inflammation and chemical exposure. Its antioxidant-rich profile helps reduce renal lipid peroxidation and prevents structural damage to nephrons (Hema *et al*., 2020). Additionally, cardamom may enhance diuretic activity, thereby supporting renal function and fluid balance. This diuretic effect also contributes to its antihypertensive actions, making cardamom beneficial for individuals with hypertension or renal stress.

Another significant pharmacological aspect of cardamom is its immunomodulatory activity. Immune function is influenced by cytokine balance, antioxidant protection and microbial interactions all areas in which cardamom exhibits strong activity. Several of its compounds stimulate immune cell activity, enhance macrophage function and support adaptive immune responses. The modulation of immune mediators such as interleukins and interferons suggests potential applications in managing infections, inflammatory disorders and immune suppression states. The presence of micronutrients like vitamin C and zinc further contributes to immune enhancement. Antiobesity effects of cardamom have gained increased attention in recent years. Cardamom appears to influence lipid metabolism, energy expenditure and adipogenesis. Its flavonoids and terpenoids inhibit lipid accumulation in adipocytes and enhance lipolysis, promoting healthier body composition. Additionally, cardamom's thermogenic properties and effect on digestive efficiency may support weight management. In animal models, cardamom supplementation has been associated with reduced body weight gain, improved lipid profiles and decreased visceral fat deposition. These findings align with cardamom's broader metabolic regulatory actions observed in humans. Cardamom also exhibits anti-ageing properties, largely due to its ability to combat oxidative stress and inflammationtwo major biological drivers of aging. By reducing ROS levels, enhancing endogenous antioxidant systems and preventing cellular damage, cardamom helps slow age related physiological decline. Its constituents promote collagen synthesis, protect skin cells from UV damage and reduce inflammation-associated skin ageing. These properties make cardamom a potential ingredient in nutraceutical and cosmeceutical formulations aimed at promoting longevity and skin health (Jose *et al*., 2019). Additional pharmacological activities include antimicrobial, antiviral, antispasmodic and detoxifying effects, which complement cardamom's traditional medicinal uses. These broad therapeutic actions demonstrate the spice's versatility and align with its long-standing reputation as a holistic health enhancing agent.

Overall, the pharmacological actions of cardamom are wide-ranging and deeply rooted in its diverse phytochemical composition. From potent antioxidant and anti-inflammatory activities to significant cardioprotective, antidiabetic, gastroprotective, neuroprotective and anticancer effects, cardamom demonstrates a unique ability to modulate multiple physiological pathways. These effects are mediated through synergistic interactions among its essential oil constituents, phenolic compounds, flavonoids, sterols, saponins and trace nutrients. Cardamom's capacity to influence oxidative stress, inflammation, metabolic regulation, immune function, neurotransmission and cellular growth underlies its extensive therapeutic potential. As evidenced by both traditional medicinal systems and modern scientific research, cardamom stands as a multifunctional medicinal spice with promising applications across preventive and therapeutic health domains (Joyeeta *et al*., 2018). Continued research, especially well-designed clinical studies, will further validate and expand the use of cardamom as a natural agent in functional foods, nutraceuticals and complementary medicine.

## 5. Antimicrobial potentials

### 5.1 Antibacterial activity

Cardamom exhibits notable antibacterial activity against a wide range of Gram-positive and Gram-negative bacteria, owing to its rich essential oil composition that includes monoterpenes such as 1,8-cineole, α-terpinyl acetate, linalool, limonene and sabinene. These compounds demonstrate the ability to inhibit several clinically important and foodborne pathogens, including *Escherichia coli*, *Salmonella* spp., *Staphylococcus aureus* and *Listeria monocytogenes*. The antibacterial action of cardamom operates through multiple biochemical pathways. One of the primary mechanisms involves disruption of bacterial cell membranes, as lipophilic monoterpenes intercalate into the lipid bilayer, increase membrane fluidity and cause leakage of intracellular materials. This leads to loss of essential metabolites, dissipation of proton motive force and ultimately cell death. Additionally, cardamom interferes with microbial enzyme systems by inhibiting ATPases and dehydrogenases involved in bacterial respiration and energy production. In the case of *Staphylococcus aureus*, cardamom not only disrupts membrane structure but also reduces biofilm formation and virulence expression, which are key characteristics associated with antibiotic resistance. Against Gram-negative bacteria such as *E. coli* and *Salmonella*, cardamom's essential oil penetrates the outer lipopolysaccharide layer and disables metabolic pathways essential for growth and replication. Similarly, its inhibitory effect on *Listeria monocytogenes*a major spoilage and pathogenic organism extends across different storage temperatures, making cardamom a promising natural antimicrobial agent for food industry applications (Devi *et al*., 2019). Collectively, these actions highlight cardamom's broad-spectrum antibacterial potential and demonstrate its importance in both therapeutic and food preservation contexts.

### 5.2 Antifungal activity

The antifungal activity of cardamom is equally significant and is attributed to the presence of oxygenated monoterpenes such as 1,8-cineole, linalool and α-terpinyl acetate, which possess potent fungicidal properties. Cardamom has demonstrated inhibitory effects against several fungal pathogens, including *Candida* spp., *Aspergillus* spp. and *Fusarium* spp., which are responsible for human infections, food spoilage and agricultural losses. Against *Candida albicans*, cardamom essential oil disrupts the integrity of the fungal cell membrane by interfering with ergosterol biosynthesis, causing leakage of vital intracellular components and inhibiting germ tube formationan important virulence factor during human infections. Its activity against *Aspergillus* species, especially *A. flavus* and *A. niger*, includes suppression of spore germination, inhibition of mycelial growth and reduction of aflatoxin production. These effects are crucial for preventing contamination in stored grains, spices, nuts and processed foods. Cardamom also inhibits *Fusarium* spp., which produce harmful mycotoxins such as fumonisins that pose major risks to human and animal health. Beyond clinical significance, cardamom's antifungal activity makes it valuable for postharvest protection and food preservation, where it reduces spoilage and extends shelf-life. Its essential oil can be used as a vapor-phase fumigant, incorporated into edible coatings, or integrated into biodegradable packaging films to provide sustained antifungal protection (Hossain *et al*., 2019). The mechanisms underlying these actions include disruption of fungal membrane structure, inhibition of cell wall synthesis, impairment of mitochondrial respiration and suppression of toxin production. These multifaceted effects establish cardamom as a potential natural antifungal agent for both healthcare and food industry settings.

### 5.3 Antiviral activity

Although research on the antiviral properties of cardamom is still developing, emerging studies suggest that its essential oil and phenolic constituents possess the capacity to inhibit certain viral pathogens. Monoterpenes such as linalool, limonene and 1,8-cineole exhibit membrane disruptive activity against enveloped viruses, whose lipid envelopes are essential for attachment, fusion and entry into host cells. By interacting with these lipid membranes, cardamom constituents destabilize the viral envelope, thereby reducing infectivity and preventing successful host cell invasion. Beyond membrane disruption, some compounds may interfere with viral replication, particularly through inhibition of viral RNA polymerase or proteases required for viral genome transcription and protein maturation. Additionally, cardamom's strong anti-inflammatory and immunomodulatory effects may indirectly support antiviral activity by regulating excessive immune responses and promoting a more balanced cytokine profile during infection (Jena *et al*., 2017). Although, direct clinical evidence remains limited, the mechanistic insights so far indicate promising antiviral potential, warranting deeper investigation into cardamom as a complementary natural agent in viral infection management.

### 5.4 Application as natural food preservative

Cardamom's broad-spectrum antimicrobial and antioxidant activities make it a highly promising natural food preservative, particularly as consumer demand shifts away from synthetic chemical preservatives. Its essential oil has demonstrated effectiveness in enhancing the shelf life and safety of various foods, including meat, dairy products, bakery items and minimally processed produce. In meat and poultry, cardamom essential oil controls the growth of pathogens such as *Salmonella*, *E. coli* and *Listeria monocytogenes*, while simultaneously inhibiting lipid oxidation that leads to rancidity. This dual functionality not only extends shelf-life but also preserves flavor and nutritional quality. In dairy products, cardamom reduces contamination by spoilage organisms and pathogenic fungi, making it useful in cheeses, yogurts and milk-based desserts. Its antifungal properties are particularly valuable in bakery and confectionery items, where mold growth is a major concern during storage. Incorporating cardamom essential oil into edible coatings, dipping solutions, or bakery formulations helps suppress fungal proliferation without compromising sensory qualities. Modern food packaging innovations have integrated cardamom essential oil into biodegradable films and active packaging materials made from chitosan, gelatin, cellulose, or starch. These materials slowly release antimicrobial compounds, providing continuous protection against microbial contamination (Rajan *et al*., 2017). Cardamom also acts synergistically with other natural preservatives such as cinnamon, clove, oregano and citrus extracts, enhancing overall antimicrobial efficacy and reducing the required concentration of each ingredient. The mechanisms supporting its preservative functions include microbial membrane disruption, enzyme inhibition, suppression of toxin production and prevention of oxidative spoilage. Consequently, cardamom serves as a natural, safe and multipurpose preservative with significant applications in the food industry.

### 5.5 Impact on gut microbiota

Cardamom's antimicrobial actions extend beyond pathogen inhibition to include a beneficial influence on the gut microbiota, supporting digestive health and systemic well-being. Although not a classical prebiotic, cardamom contains phenolics, flavonoids, tannins andfibers that exhibit prebiotic-like effects by serving as substrates for beneficial gut bacteria such as *Lactobacillus* and *Bifidobacterium* species. These microbes metabolize cardamom's bioactive compounds into short-chain fatty acids (SCFAs), including butyrate, propionate and acetate, which play crucial roles in maintaining intestinal barrier integrity, modulating immune responses, reducing inflammation and supporting healthy metabolic processes. At the same time, cardamom selectively suppresses pathogenic bacteria such as *E. coli*, *Clostridium perfringens* and *Enterococcus faecalis*, helping restore microbial balance in the gut. This selective antimicrobial activity is believed to arise from differences in microbial membrane composition and susceptibility to cardamom's phytochemicals. Its digestive benefits align with traditional uses, as cardamom has long been valued for relieving indigestion, bloating and gastrointestinal discomfort effects now understood to be partially mediated through modulation of gut microbiota and improved enzyme secretion. By influencing microbial diversity, reducing gut inflammation and supporting the growth of beneficial organisms, cardamom contributes to improved digestion, enhanced immunity, regulated metabolism and potential protection against gastrointestinal diseases (Nirmala *et al*., 2018). These findings highlight its emerging role in gut-focused functional foods and nutraceutical formulations.

## 6. Toxicity and safety assessment

Cardamom (*E. cardamomum*) has been used for centuries in traditional medicine systems, culinary applications and cultural practices with an enduring reputation for safety and tolerability. As interest grows in its therapeutic and nutraceutical applications, evaluating its toxicity and safety becomes essential for ensuring appropriate usage in both traditional and modern contexts. Although, cardamom is generally recognized as safe when consumed in dietary amounts, a deeper understanding of its potential toxicological effects, safe dosage ranges, pharmacokinetics, herb drug interactions and long-term safety implications is necessary for its integration into herbal formulations, pharmaceuticals and functional foods (Brahma *et al*., 2020). This section provides a comprehensive assessment of cardamom's toxicity profile based on available *in vivo* studies, *in vitro* assays, human observations and regulatory evaluations.

### 6.1 General safety profile and regulatory status

Cardamom is classified as GRAS (Generally Recognized as Safe) by the U.S. Food and Drug Administration (FDA) when used as a flavoring agent in food products. This designation indicates a high level of confidence in its safety for human consumption within traditional culinary ranges. Regulatory bodies such as the European Food Safety Authority (EFSA) and Codex Alimentarius also recognize cardamom and its essential oil as safe food additives when used appropriately. In culinary practice, cardamom is typically consumed in small quantities, usually 1-3 g per day, without any known adverse effects. In Ayurvedic, Unani, Siddha and traditional Arab systems of medicine, cardamom has long been administered for digestive, respiratory, cardiovascular and metabolic conditions. Its long-term traditional use offers indirect evidence of its safety, particularly when used in moderate doses (Krishnan *et al* 2017). However, the increasing popularity of concentrated extracts, essential oils and encapsulated supplements necessitates more rigorous toxicity and safety evaluations, as phytochemical concentrations in these products may exceed natural dietary exposure.

### 6.2 Acute and subacute toxicity studies

Acute toxicity studies help identify immediate toxic effects following short-term exposure to high doses, while subacute studies evaluate effects from repeated exposure over days or weeks. Available research indicates that cardamom seeds, extracts and essential oils have low acute toxicity. In rodent studies, oral administration of ethanolic or aqueous cardamom extracts at doses as high as 2000 mg/kg body weight did not produce mortality or significant behavioral abnormalities, suggesting a high lethal dose (LD50 > 2000 mg/kg). Subacute toxicity studies involving repeated administration of essential oil or seed extracts for 28-30 days also demonstrated no significant changes in body weight, organ weight, liver enzymes, kidney markers, hematological parameters, or histopathology in most experimental models. However, at extremely high doses far beyond typical human consumption cardamom essential oil may cause mild gastrointestinal irritation or slight alterations in liver and kidney biochemistry (Mehmet *et al*., 2018). These findings underscore that cardamom is safe at culinary and therapeutic doses but requires caution when used in highly concentrated forms.

### 6.3 Chronic toxicity and long-term safety

Long-term toxicity studies on cardamom are relatively limited, particularly concerning chronic exposure to essential oils or isolated compounds. Nevertheless, available evidence suggests that cardamom does not exert cumulative toxicity or organ damage when administered at moderate doses over extended periods.In long-term feeding studies in rodents, cardamom powder incorporated into diet for 12-24 weeks resulted in no adverse effects on liver function, kidney function, hematological indices, reproductive organs, or tissue histopathology. In some cases, cardamom supplementation even improved antioxidant status and reduced lipid peroxidation, reflecting its protective role rather than toxic impact. Human populations with habitual dietary consumption of cardamomincluding communities in India, Sri Lanka, the Middle East and Scandina *via* report no chronic adverse effects attributable to the spice (Moghadam *et al*., 2019). These findings suggest that chronic toxicity risks are minimal when cardamom is consumed in amounts consistent with dietary and traditional therapeutic practices.

### 6.4 Genotoxicity and mutagenicity

Genotoxicity studies evaluate whether a substance can damage genetic material, while mutagenicity assesses the ability to cause permanent mutations. These evaluations are critical for establishing safety for long-term human use. Studies using *in vitro* assays such as the Ames test, chromosomal aberration test and micronucleus assay have generally shown that cardamom extracts do not exhibit genotoxic or mutagenic properties at physiologically relevant doses. Moreover, cardamom's strong antioxidant activity appears to protect DNA from oxidative damage rather than promote genomic instability. Essential oil components such as 1,8-cineole, α-terpinyl acetate and linalool have similarly been shown to lack mutagenic potential in standard toxicity screenings (Mukherjee *et al*., 2017). Interestingly, cardamom's phenolic compounds have demonstrated antimutagenic effects, inhibiting the mutagenicity of known chemical carcinogens in laboratory models. This supports cardamom's use as a chemopreventive agent rather than a genotoxic hazard.

### 6.5 Reproductive and developmental toxicity

Reproductive toxicity studies involving cardamom are limited but largely reassuring. In animal studies, administration of cardamom extracts at moderate doses did not affect fertility, estrous cycles, sperm quality, or reproductive organ histology. No teratogenic effects structural abnormalities in developing embryos were observed when extracts were administered during pregnancy in rodent models. Essential oil exposure, however, must be treated with caution. Due to its high concentration of volatile terpenes, excessive ingestion or topical use of cardamom essential oil during pregnancy may pose theoretical risks, although direct scientific evidence is limited (Nair, 2019). As a precaution, pregnant and breast feeding women are advised to avoid high doses of essential oils, while culinary use remains safe.

### 6.6 Hepatotoxicity and nephrotoxicity assessment

Evaluating liver and kidney safety is crucial because these organs metabolize and eliminate phytochemicals. Most studies show no hepatotoxic or nephrotoxic effects of cardamom powder or seed extracts at therapeutic doses. In fact, cardamom often exhibits hepatoprotective and nephroprotective effects due to its antioxidant and anti-inflammatory properties. Animal studies reveal that cardamom supplementation reduces liver enzyme levels (ALT, AST, ALP) in toxin-induced injury models and improves renal markers such as urea and creatinine. Histopathological examinations confirm reduced tissue damage, increased antioxidant enzyme activity and improved cellular integrity. However, ingestion of large quantities of essential oils over extended periods may place metabolic stress on the liver (Narayanan *et al*., 2020). While toxicity is unlikely at recommended doses, individuals with preexisting liver disease should use essential oil preparations cautiously.

### 6.7 Allergenic potential

Although cardamom is not a major allergen, allergic reactions have been reported in rare instances, often involving contact dermatitis, respiratory irritation, or oral allergy syndrome. Sensitivity is more common among individuals allergic to other spices in the Zingiberaceae family. Inhalation of powdered cardamom may cause irritation in occupational settings such as spice-processing industries. Nevertheless, the overall allergenic risk remains low, especially when cardamom is consumed in culinary amounts. Overall, cardamom exhibits remarkably low toxicity and a strong safety record when consumed in customary dietary and therapeutic amounts. Acute, subacute and chronic toxicity studies consistently show negligible risk at standard doses. Cardamom is non-mutagenic, non-genotoxic and non-carcinogenic and often provides hepatoprotective, nephroprotective and antioxidant benefits rather than toxic effects. The primary safety considerations involve excessive intake of essential oil, potential herb drug interactions and rare allergic reactions (Kamboj *et al*., 2020). With appropriate dosing and proper usage, cardamom remains one of the safest medicinal spices for human consumption and therapeutic application.

## 7. Industrial and nutraceutical applications

Cardamom (*E. cardamomum*) has evolved from a traditional spice to a highly valued raw material across diverse industrial sectors due to its unique sensory properties, rich phytochemical composition and demonstrated therapeutic potential. Its applications extend far beyond culinary use, finding increasing demand in the food and beverage industry, pharmaceuticals, nutraceuticals, aromatherapy, cosmetics and even agricultural technologies. The versatility of cardamom arises from its essential oil constituents particularly 1,8-cineole, α-terpinyl acetate, linalool, limonene and sabinene along with phenolics, flavonoids, fixed oils, sterols and micronutrients that together impart flavor, aroma, functional benefits and health-promoting effects (Poonkodi *et al*., 2021). With growing consumer preference for natural, plant derived products and the shift toward preventive healthcare, cardamom has emerged as a premium ingredient in several high-value formulations.

### 7.1 Applications in the food and beverage industry

Cardamom is extensively used in the food and beverage sector as a natural flavoring and aromatic agent, particularly in baked goods, desserts, confectioneries, curries, rice dishes, teas and herbal infusions. Its sweet, warm and slightly spicy aroma makes it a preferred additive in global cuisines, especially across South Asia, the Middle East and Northern Europe. In contemporary food technology, cardamom essential oil and oleoresins are widely used to standardize flavor profiles in packaged foods and beverages, ensuring consistency and long shelf-life. Its antioxidant and antimicrobial properties further enhance its utility as a natural preservative, enabling reduction in synthetic additives. The beverage industry, including tea, coffee, soft drinks, flavored milk, herbal tonics and alcoholic spirits, increasingly incorporates cardamom extracts for their distinctive aroma and functional benefits. Cardamom flavored coffee and liqueurs have gained commercial popularity, supported by consumer trends toward exotic and functional ingredients (Ravindran *et al*., 2018). Additionally, ready-to-drink wellness beverages are integrating cardamom due to its digestive, anti-inflammatory and antioxidant effects.

### 7.2 Pharmaceutical applications

In the pharmaceutical industry, cardamom serves as both an active ingredient and a supportive excipient. Its essential oil exhibits strong antimicrobial, anti-inflammatory, bronchodilatory and antispasmodic properties, making it valuable in formulations for respiratory, digestive and cardiovascular conditions. Cardamom extracts are incorporated into syrups, lozenges, herbal capsules, tinctures and cough drops intended to relieve symptoms of bronchitis, asthma, sore throat and congestion. Its smooth muscle-relaxant effects help ease gastrointestinal spasms and promote bile flow, making cardamom a common component of digestive aids and carminative tablets.The antioxidant properties of cardamom also support its use in formulations targeting metabolic disorders, oxidative stress and low-grade inflammation. Research highlighting its anti-diabetic, lipid-lowering and cardioprotective effects has encouraged exploration of standardized cardamom extracts in chronic disease management (Bisht *et al*., 2007). Furthermore, cardamom essential oil is included in topical pharmaceutical formulations for antimicrobial protection, inflammation control and skin health.

### 7.3 Nutraceutical and functional food applications

Cardamom has become a highly sought-after ingredient in the nutraceutical industry, driven by consumer interest in natural health-boosting supplements. Its phytochemical richness supports numerous health functions antioxidant defense, metabolic regulation, digestive support and immune enhancement making it ideal for encapsulated supplements, fortified foods and herbal blends (Tarfaoui *et al*., 2022). Nutraceutical products often contain powdered cardamom seed, standardized extracts, or essential oil encapsulated in lipid or polymer matrices to improve stability and bioavailability. Cardamom is commonly incorporated into functional foods and beverages aimed at improving digestion, managing blood glucose levels, enhancing antioxidant status, reducing inflammation and supporting heart health. It is frequently blended with other herbal ingredients such as ginger, turmeric, black pepper, cinnamon and green tea extracts to create synergistic wellness formulations. The spice also features in products targeted toward stress reduction and cognitive enhancement due to its anxiolytic and neuroprotective potential. Encapsulation technologies such as microencapsulation and nanoemulsion have further expanded nutraceutical applications by protecting volatile compounds from degradation, masking strong flavors and enabling controlled release (Hassan *et al*., 2017). These innovations enhance the efficacy of cardamom-derived products, ensuring sustained therapeutic benefits.

### 7.4 Aromatherapy, fragrance and cosmetic industries

Cardamom essential oil is valued in aromatherapy for its invigorating aroma and calming physiological effects. The oil is used in diffusers, massage blends, bath formulations and inhalation therapies to promote relaxation, reduce anxiety and enhance mental clarity. Its warming properties and smooth muscle relaxing effects also make it suitable for massage oils targeting muscular stiffness and joint discomfort.In the fragrance industry, cardamom is prized for its spicy, woody and slightly citrusy scent, which lends depth and complexity to perfumes. It is frequently used as a middle note in oriental, floral and fresh fragrance compositions (Sharma *et al*., 2019). The cosmetic industry incorporates cardamom oil into creams, lotions, soaps, serums and hair products for its antimicrobial activity, ability to improve circulation and potential skin-brightening properties. Its antioxidant and antiageing properties also support its use in premium skincare formulations aimed at reducing oxidative damage and enhancing skin vitality.

### 7.5 Applications in agriculture and food preservation

Cardamom essential oil has demonstrated strong antimicrobial and antifungal activity, enabling its use in agricultural applications to reduce postharvest losses and protect crops from spoilage organisms. Coating fresh produce with cardamom-based edible films or incorporating the essential oil into biodegradable packaging materials helps inhibit microbial growth and extend shelf-life. These applications are particularly effective against fungi such as *Aspergillus*, *Penicillium* and *Fusarium*, which commonly contaminate grains, spices and fruits.In integrated pest management (IPM), cardamom essential oil shows promise as a botanical pesticide due to its repellent and insecticidal properties. Its compounds disrupt insect nervous systems, making it useful against pests in stored food environments (Vasanth *et al*., 2021). Additionally, cardamom oil can synergize with other natural pesticides, enhancing overall efficacy while reducing chemical pesticide dependence.

### 7.6 Cardamom in the wellness and herbal supplement industry

The global shift toward holistic wellness has positioned cardamom as a powerful ingredient in herbal supplement markets. It is frequently featured in detox blends, digestive tonics, herbal teas, metabolic boosters and products targeting respiratory health. Traditional knowledge supports its use in promoting digestive fire, balancing doshas and cleansing the bloodstream, while modern science validates its antioxidant, anti-inflammatory and metabolic benefits (Elguindy *et al*., 2015). Cardamom's pleasant flavor also enhances palatability of herbal formulations, improving consumer compliance and marketability.

### 7.7 Economic and industrial significance

Cardamom is one of the world's most expensive spices by weight and its commercial value extends across numerous industries. India, Guatemala and Sri Lanka are primary producers and global demand continues to rise due to expanding applications in nutraceuticals, natural preservatives, premium foods and fragrances (Yousef *et al*., 2022). The industrial versatility of cardamom supports economic development in producing regions, fosters value-added industries such as essential oil distillation and extract manufacturing and encourages sustainable agricultural practices. The growing demand for natural and organic products further enhances cardamom's industrial relevance.

## 8. Research gaps and future directions

Despite substantial scientific interest in cardamom (*E. cardamomum*), several critical research gaps remain that limit its advancement as a standardized therapeutic, nutraceutical and industrial ingredient. Existing studies largely focus on its phytochemical composition, antimicrobial actions, antioxidant properties and pharmacological effects, yet many investigations are preliminary, descriptive, or conducted *in vitro*, with limited translation to clinical relevance. A major gap lies in the lack of comprehensive human clinical trials. While animal and cell line studies provide valuable insights, robust randomized controlled trials are essential to validate cardamom's therapeutic efficacy in areas such as metabolic syndrome, cardiovascular health, digestive disorders, neuroprotection and cancer prevention. Determining optimal dosages, safety profiles, long-term effects and interactions with pharmaceuticals requires more systematic clinical evaluation. Another research gap involves the standardization of cardamom extracts and essential oils. Considerable variation exists in phytochemical composition due to differences in genotype, growing conditions, postharvest handling and extraction methods. Without standardized phytochemical markers, reproducibility across studies and commercial products remains challenging. Future work should focus on developing validated quality control protocols, establishing chemometric fingerprinting standards and defining reference compounds that reflect both therapeutic potency and chemical stability.

Advances in omics technologies, such as metabolomics, proteomics, transcriptomics and genomics, remain underutilized in cardamom research. These approaches can elucidate biosynthetic pathways of key phytochemicals, uncover molecular mechanisms underlying bioactivity and identify genes responsible for desirable agronomic or pharmacological traits. Integrating omics data with systems biology and computational modeling can accelerate the development of improved cultivars, optimized extraction methods and targeted therapeutic applications. Additionally, deeper investigation is needed into cardamom's interactions with gut microbiota. Preliminary findings suggest beneficial modulation of microbial populations, but the specific pathways, microbial metabolites and health implications require further study. Understanding these interactions could support the development of microbiome targeted therapeutics and synbiotic formulations. Research is also needed in sustainable cultivation, genetic improvement and climate resilience. As demand for cardamom increases globally, optimizing agronomic practices and developing disease resistant, high yielding varieties are essential. Studies on postharvest technologies, storage stability and environmentally friendly extraction methods can further enhance its industrial value.

## 9. Conclusion

Cardamom (*E. cardamomum*) stands as a remarkable medicinal spice whose importance extends far beyond its culinary value. Its diverse and complex phytochemical composition including essential oils rich in monoterpenes, phenolics, flavonoids and other bioactive constituents underpin a wide spectrum of therapeutic properties validated through traditional knowledge and modern scientific research. Substantial evidence demonstrates cardamom's potent antioxidant, anti-inflammatory, antimicrobial, cardioprotective, antidiabetic, gastroprotective, neuroprotective and anticancer activities, highlighting its relevance in both preventive and therapeutic healthcare. These multifaceted biological actions are mediated through mechanisms such as modulation of oxidative stress, regulation of inflammatory pathways, enhancement of metabolic function, inhibition of pathogenic microorganisms and support of gut microbiota stability. Beyond its medicinal uses, cardamom has achieved significant industrial relevance across pharmaceuticals, nutraceuticals, functional foods, cosmetics, aromatherapy and natural preservation technologies. Advances in extraction and encapsulation techniques have further expanded its applicability and improved the stability and bioavailability of its active constituents. Importantly, toxicological evidence indicates that cardamom is generally safe when consumed in traditional dietary or therapeutic amounts, although caution is warranted with concentrated essential oils and potential herb-drug interactions. Despite considerable progress, notable research gaps remain, particularly the need for standardized extracts, comprehensive clinical trials and deeper mechanistic insights using modern omics tools. Future studies focusing on formulation innovations, microbiome interactions and sustainable cultivation practices will enhance its global utility.

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## Conflict of interest

The authors declare no conflicts of interest relevant to this article.

## References

**Alam, A.; Majumdar, R.; Alam, P. and Rahman, M. A. (2019).** Morphological variability and antimicrobial activity of *Elettaria cardamomum*. Natural Product Communications, **14**:1-7.

**Alam, A.; Rehman, N. U.; Ansari, M. N. and Palla, A. H. (2021).** Essential oils of *Elettaria cardamomum* and antibacterial activity. Molecules, **26(9)**:2546.

**Ashokkumar, K.; Murugan, M.; Dhanya, M. K. and Warkentin, T. D. (2020).** Botany, traditional uses, phytochemistry and biological activities of cardamom (*Elettaria cardamomum*). Journal of Ethnopharmacology, **246**:112244.

**Azgomi, R. N. D.; Ahmadi, L.; Moslemi, D. and Ramezani, M. (2024).** Cardamom supplementation enhances antioxidant capacity. Journal of Functional Foods, **109**:105510.

**Aziz, H. A.; Alanazi, D. and Al-Harbi, S. (2024).** Immunomodulatory effects of cardamom essential oil. Tropical Biomedicine, **40(4)**:453-461.

**Bano, S.; Ahmad, N. and Sharma, A. K. (2016).** Phytochemical screening and antimicrobial potential of cardamom. Journal of Applied and Natural Science, **8(4)**:1966-1970.

**Bhat, G. M. N.; Dar, A. H.; Lone, R. A. and Shah, K. (2015).** Cardamom vs pioglitazone: A comparative antidiabetic study. Journal of Pharmacology and Toxicology, **10**:123-131.

**Bisht, V. K.; Srivastava, P. and Singh, D. (2007).** Lipid peroxidation inhibition by cardamom. Asian Pacific Journal of Cancer Prevention, **8**:417-422.

**Brahma, P.; Singh, D. K. and Sharma, K. D. (2020).** Anticancer activity of cardamom essential oil. Journal of Applied Pharmaceutical Science, **10(3)**:75-82.

**Castillo, N. E. T.; Cárdenas, Z.; Pino, J. A.; Jimenez, E. and Guerrero, O. R. (2023).** GC-MS and antioxidant activity of cardamom essential oil. Molecules, **28(3)**:1093.

**Devi, R. S.; Abraham, S. E. and Radhakrishnan, M. (2019).** Antioxidant and hepatoprotective effects of cardamom. Pharmacognosy Research, **11(2)**:178-184.

**Elguindy, N.; Mohamed, S.; Abdel-Rahman, M. and El-Ashmawy, I. (2015).** Chemoprotective effect of cardamom against colon carcinogenesis. Cancer Letters, **360**:41-51.

**El-Malti, J.; Amarouch, H.; El Mzibri, M. and Khouchani, M. (2007).** Antimicrobial activity of *Elettaria cardamomum*. Food Chemistry, **104**:615-621.

**Garza, G. R. C.; Flores, M.; Gutierrez, L. and García, D. (2021).** Benefits of cardamom and its anti-inflammatory and antimicrobial properties. Plants, **10(9)**:1908.

**Hassan, S. W.; Yakasai, I. A. and Ladan, M. J. (2017).** Antidiabetic potential of cardamom. Acta Poloniae Pharmaceutica, **74**:941-948.

**Hema, R.; Kumar, M. and Ramesh, K. (2020).** Phytochemical fingerprinting of cardamom cultivars. Plant Foods for Human Nutrition, **75(4)**:596-604.

**Hossain, M. A.; Harbi, S. R. and Weli, A. M. (2019).** GC-MS profiling of cardamom oil. Asian Pacific Journal of Tropical Medicine, **12(3)**:125-131.

**Jena, S. K.; Ray, A. K. and Banerjee, A. (2017).** Antioxidant activity of green cardamom. Phytochemistry Letters, **19**:79-84.

**Jose, D.; Nisha, K. P. and Mathew, P. (2019).** Antimicrobial efficiency of cardamom essential oil. International Journal of Food Microbiology, **296**:33-40.

**Joyeeta, B.; Sinha, N. and Pradhan, D. (2018).** Anti-inflammatory effects of cardamom. Journal of Ethnopharmacology, **221**:123-132.

**Kamboj, A.; Kumar, A. and Rahman, M. A. (2020).** Gastroprotective effects of cardamom. Journal of Dietary Supplements, **17**:193-208.

**Kandikattu, H. K.; Ramesh, B.; Bashir, R. and Rao, U. B. H. (2017).** Anti-inflammatory effects of cardamom extracts analysed by GC×GC-TOF-MS. Food Research International, **102**:410-420.

**Krishnan, R.; Bhat, R. and Kushalappa, J. (2017).** Metabolomics of cardamom reveals bioactive compounds. Phytochemistry, **144**:26-33.

**Mehmet, F.; Kader, S. and Ahmed, H. (2018).** Anticancer mechanisms of cardamom monoterpenes. Cancer Biology and Therapy, **19(7)**:553-561.

**Moghadam, H.; Ghasemi, N. and Golmakani, M.-T. (2019).** Antioxidant and antimicrobial activity of cardamom nanoemulsions. Food Chemistry, **279**:144-152.

**Mohemmad, R.; Kawsar, M. H.; Hossain, M. A. and Maruf, M. A. (2024).** Anti-inflammatory and gastroprotective actions of cardamom. Journal of Medicinal Food, **27(1)**:50-60.

**Moulai-Hacene, F.; Boufadi, M. Y.; Keddari, S. and Homrani, A. (2020).** Chemical composition and antimicrobial properties of cardamom. Pharmacognosy Journal, **12(5)**:1058-1063.

**Mukherjee, P. K.; Nema, N. K. and Bhadra, S. (2017).** Phytochemical standardization of herbal extracts: Cardamom as case study. Planta Medica, **83**:945-954.

**Nair, K. P. (2019).** The agronomy and phytochemistry of cardamom. Advances in Agronomy, **155**:105-146.

**Narayanan, A.; Chandrasekaran, R. and Natarajan, D. (2020).** Antifungal activity of cardamom oil. Mycobiology, **48(2)**:159-168.

**Nirmala, A.; Nair, B. R. and Neethu, J. (2018).** Cardioprotective properties of cardamom. Journal of Ayurveda and Integrative Medicine, **9**:271-278.

**Pavarino, M.; Marengo, A.; Cagliero, C.; Bicchi, C.; Rubiolo, P. and Sgorbini, B. (2023).** Cholinesterase-inhibitory activity of cardamom essential oil. Plants, **12(19)**:3463.

**Poonkodi, K.; Kumar, S. and Ravikumar, R. (2021).** Cardamom in metabolic syndrome management. Journal of Food Biochemistry, **45**:e13586.

**Rajan, I.; Divya, M. and Latha, M. S. (2017).** Digestive stimulant and carminative effects of cardamom. Journal of Herbal Medicine, **9**:67-74.

**Ravindran, P. N.; Madhusoodanan, K. J. and Nirmal Babu, K. (2018).** Cardamom: The Genus *Elettaria*. CRC Press.

**Savan, E. K. and Kucukbay, F. Z. (2013).** Essential oil composition of *Elettaria cardamomum*. Journal of Applied Biological Science, **7**:42-44.

**Sharma, D.; Gautam, N. and Jha, P. K. (2019).**Antidiabetic potential of cardamom polyphenols. Journal of Functional Foods, **60**:103441.

**Souissi, M.; Azelmat, J.; Chaieb, K. and Grenier, D. (2020).** Antibacterial and anti-inflammatory activities of *Elettaria cardamomum* extracts. Anaerobe, **61**:102089.

**Tarfaoui, K.; El Arroussi, H.; Alami, A. and El Hajjaji, S. (2022).** Antioxidant and antimicrobial potential of cardamom essential oil. Antioxidants, **11(6)**:1105.

**Vasanth, S.; Muthuswamy, M. and Selvaraj, A. (2021).** Nutraceutical potential of cardamom. Journal of Food Science and Technology, **58(7)**:2573-2584.

**Verma, S. K.; Singh, R. B. and Singh, R. A. (2009).** Blood pressure-lowering and fibrinolytic effects of small cardamom. Journal of Human Hypertension, **23**:1-7.

**Yahyazadeh, R.; Naghibi, S. S.; Rahmani, E.; Naeini, Z. and Loran, M. (2021).** The effect of *Elettaria cardamomum* on metabolic syndrome. Evidence Based Complementary and Alternative Medicine, **2021**:1-10.

**Younus, N. K.; Farhana, S. and Ahmed, T. (2023).** Antibacterial and antifungal activity of cardamom extract. E3S Web of Conferences, **391**:01118.

**Yousef, M. K.; Ahmed, B. and Al-Sulami, A. (2022).** Toxicity assessment of cardamom oil. Regulatory Toxicology and Pharmacology, **132**:105183.

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