JOURNAL OF PHARMA INSIGHTS AND RESEARCH ISSN NO. 3048-5428

REVIEW ARTICLE

A Review on Pharmacological Properties and Therapeutic Applications of *Zingiber officinale*

Ramakrishna S*[1], Narayana Murthy G[2], Monika V[3], Likhitha K[4]

[1] *Assistant Professor, Department of Pharmacognosy, National College of Pharmacy, Shivamogga, Karnataka, India*
[2] *Principal and Professor, Department of Pharmacognosy, National College of Pharmacy, Shivamogga, Karnataka, India*
[3] *UG Scholar, Department of Pharmacognosy, National College of Pharmacy, Shivamogga, Karnataka, India*
[4] *Lecturer, Department of Pharmacognosy, National College of Pharmacy, Shivamogga, Karnataka, India*

Publication history: Received on 1st Mar 2025; Revised on 14th March 2025; Accepted on 15th March 2025

Article DOI: 10.69613/7p9b1v17

Abstract: The usage of Ginger (*Zingiber officinale*) has deep roots in traditional healing systems, particularly Ayurveda and Traditional Chinese Medicine. The rhizome's therapeutic potential is mainly due to its phytochemical constituents like gingerols, shogaols, paradols, and essential oils. Modern pharmacological studies have proven the multiple biological activities of ginger, including anti-inflammatory, antioxidant, antiemetic, and immunomodulatory effects. It shows promising results in managing various pathological conditions such as cardiovascular diseases, cancer, metabolic disorders, and inflammatory diseases. Clinical evidence supports its efficacy in treating chemotherapy-induced nausea, postoperative complications, and pregnancy-related morning sickness. The plant's bioactive compounds exhibit variable pharmacokinetic profiles, and affected by preparation methods and formulation techniques. Recent advances in delivery systems and nano-formulations have improved the bioavailability and therapeutic efficacy of ginger compounds. Although substantial evidence supports its safety profile, standardization of dosage regimens and counterweighing of drug interactions remain crucial for effective use of Ginger. The scope of ginger usage is further increased in food preservation and targeted drug delivery systems as reported in the recent literature.

Keywords: *Zingiber officinale*; Gingerols; Anti-inflammatory; Phytotherapy; Bioactive compounds.

1. Introduction

Zingiber officinale, commonly known as ginger, represents one of the most extensively utilized medicinal plants in global traditional medicine systems. This rhizomatous herb, belonging to the Zingiberaceae family, has garnered significant scientific attention due to its diverse pharmacological properties [1]. The historical significance of ginger extends beyond its culinary applications, with documented medicinal use dating back over 5000 years in ancient Chinese and Indian texts [2]. The pharmacological significance of ginger primarily derives from its complex phytochemical composition. The rhizome contains numerous bioactive compounds, particularly phenolic ketones including gingerols, shogaols, and paradols, along with essential oils that contribute to its therapeutic properties [3]. These compounds exhibit remarkable biological activities, positioning ginger as a potential therapeutic agent in modern medicine [4].

Zingiber officinale, commonly known as ginger, belongs to the monocotyledonous flowering plants within the plant kingdom (Plantae). It is a member of the vascular plants (Phylum Tracheophyta) and the class Liliopsida, and classified under the order Zingiberales. The plant belongs to the ginger family Zingiberaceae, specifically within the genus Zingiber.

Figure 1. Rhizome of *Zinziber officinale*

* Corresponding author: Ramakrishna S

2. Morphological and Microscopical Characteristics

2.1. Morphology

The rhizome, the primary medicinal part, exhibits distinctive characteristics essential for authentication and quality assessment. The mature rhizome typically measures 5-15 cm in length and 1.5-6.5 cm in width, displaying a buff-colored exterior. The surface presents multiple flat, ovate branches with characteristic bud formations at the apex. The rhizome's internal structure reveals a short, fibrous fracture pattern, accompanied by an aromatic odor and distinctively pungent taste [5].

2.2. Microscopy

The internal anatomy of ginger rhizome presents a complex arrangement of tissues. The cortical region comprises irregularly arranged parenchymatous cells with thin cell walls. A well-defined endodermis separates the stele from the cortex, each functioning as independent units. The vascular architecture features multiple closed collateral bundles embedded within cortical tissues, while the ground tissue contains oleoresin cells and starch grains, except in the endodermal region [6].

3. Phytochemical Composition

3.1. Major Chemical Constituents

Ginger shows a diverse chemical profile that includes various components in different proportions. The volatile oil comprises 1-4% of the total composition, while starch represents a substantial portion ranging from 40-60%. The lipid content accounts for approximately 10% of the composition, with fiber and proteins contributing 5% and 6% respectively. The moisture content typically remains around 10%, and resinous compounds make up 5-8% of the total composition

3.2. Bioactive compounds

The volatile oil fraction contains distinct classes of compounds, each contributing to ginger's characteristic properties and therapeutic effects. The composition of these bioactive compounds can be primarily categorized into terpene hydrocarbons and phenolic compounds.

3.2.1. Terpene Hydrocarbons

Within the essential oil fraction, monoterpene and sesquiterpene hydrocarbons constitute significant portions. The major components identified in this category include α-zingiberene, β-bisabolene, and α-farnesene, which collectively contribute to the characteristic aroma and biological activities of ginger [7].

3.2.2. Phenolic Compounds

The phenolic constituents represent the primary bioactive components of ginger, with gingerols, shogaols, and paradols being the most notable compounds in this category. These compounds are particularly interesting due to their dynamic nature during processing. Under thermal conditions, gingerols undergo transformation to form shogaols, demonstrating the complex chemical changes that occur during various processing methods [8]

Table 1. Major Bioactive Compounds in Ginger (*Zingiber officinale*) and Their Therapeutic Properties

Compound Class	Main Compounds	Major Therapeutic Properties
Gingerols	6-gingerol, 8-gingerol, 10-gingerol	Anti-inflammatory, Antioxidant, Antiemetic, Anticancer
Shogaols	6-shogaol, 8-shogaol, 10-shogaol	Neuroprotective, Anti-inflammatory, Enhanced bioavailability, Antioxidant
Paradols	6-paradol, 8-paradol	Antiproliferative, Anti-inflammatory, Antioxidant
Zingerone	-	Antidiabetic, Anti-inflammatory, Antioxidant, Neuroprotective

4. Pharmacological activities

4.1. Anti-inflammatory Properties

Ginger exhibits remarkable anti-inflammatory activity through multiple molecular mechanisms, with its active compounds playing crucial roles in modulating inflammatory responses. The bioactive components, particularly 6-shogaol, zingerone, and 8-shogaol, have demonstrated significant capabilities in modulating inflammatory pathways by inhibiting key mediators of inflammation [9]. Research has shown that 6-gingerol, a prominent compound in ginger, provides protective effects against neutrophil extracellular trap formation through phosphodiesterase inhibition, which has proven particularly beneficial in managing autoimmune conditions such as lupus [10].

The anti-inflammatory action of ginger operates through several sophisticated mechanisms. These include the inhibition of the NF-κB signaling pathway, which plays a central role in inflammatory responses. Additionally, ginger compounds effectively reduce the production of pro-inflammatory cytokines, while simultaneously modulating the activities of COX-2 and LOX enzymes. The suppression of prostaglandin synthesis further contributes to its comprehensive anti-inflammatory effects.

4.2. Cardiovascular Effects

Ginger demonstrates comprehensive cardiovascular benefits through various physiological pathways, with its active components exhibiting notable anti-hypertensive, anti-platelet, and anti-hyperlipidemic properties [11]. The cardioprotective effects of ginger manifest through multiple mechanisms, including the enhancement of nitric oxide production, which is crucial for vascular health. The herb also demonstrates effectiveness in regulating calcium channel activity, modulating blood pressure through ACE inhibition, and improving lipid metabolism, collectively contributing to its cardioprotective profile.

The impact of ginger on vascular health extends beyond basic cardiovascular functions, encompassing improvements in endothelial function and prevention of atherosclerosis. Scientific studies have documented significant reductions in arterial stiffness and enhanced peripheral circulation in subjects using ginger supplements [12]. These vascular benefits contribute to the overall cardiovascular protective effects of the herb.

4.3. Antiemetic Properties

Ginger has demonstrated remarkable antiemetic efficacy across various clinical scenarios. Its effectiveness has been well-documented in managing chemotherapy-induced nausea, postoperative nausea and vomiting (PONV), and pregnancy-related morning sickness [13]. These antiemetic properties have made ginger a valuable natural remedy in both traditional and modern medical practices.

The antiemetic effects of ginger are achieved through several chemical pathway modifications. The herb functions as a 5-HT3 receptor antagonist, effectively regulating nausea and vomiting reflexes. Additionally, ginger alters both cholinergic and serotonergic pathways, which are crucial in controlling emetic responses. The improvement of gastric emptying further contributes to its antiemetic efficacy, making it an effective solution for various forms of nausea and vomiting.

Clinical research has provided evidence supporting ginger's effectiveness in managing various forms of nausea. Studies have particularly highlighted its efficacy in reducing both the severity and frequency of chemotherapy-induced nausea. A notable finding is the decreased requirement for rescue antiemetics among patients using ginger supplements, indicating its potential as a complementary therapeutic agent [14].

4.4. Gastroprotective Effects

4.4.1. Mucosal Protection

Ginger's gastroprotective properties are manifested through multiple sophisticated mechanisms, particularly in providing gastric mucosal protection against various ulcerogenic agents. The herb has demonstrated remarkable effectiveness in protecting the gastric mucosa from damage caused by Helicobacter pylori infections, which are a primary cause of gastric ulcers. Additionally, it offers protection against damage induced by NSAIDs, which are known to cause gastric irritation and ulceration. The protective effects extend to damage caused by ethanol consumption and stress-induced gastric complications, making it a comprehensive gastroprotective agent.

4.4.2. Antioxidant effects

The gastroprotective effects of ginger are significantly enhanced by its potent antioxidant properties. These properties manifest through multiple pathways, including efficient free radical scavenging activities that help neutralize harmful oxidative species in the gastric environment. The herb also demonstrates notable capabilities in inhibiting lipid peroxidation, a process that can damage

cellular membranes. Furthermore, ginger has been shown to enhance endogenous antioxidant systems, strengthening the body's natural defensive mechanisms [15].

4.5. Metabolic Effects

4.5.1. Anti-obesity Properties

Ginger exhibits significant effects on metabolic health through various mechanisms that contribute to its anti-obesity properties. The herb has been shown to enhance thermogenesis, increasing the body's energy expenditure and promoting weight management. It effectively modulates lipid metabolism, influencing how the body processes and stores fats. Additionally, ginger helps reduce adipose tissue inflammation, a key factor in obesity-related complications. These effects are complemented by its ability to improve insulin sensitivity, making it a valuable component in metabolic health management [16].

4.5.2. Glucose Regulation

The impact of ginger on glucose metabolism is comprehensive and multi-faceted. It enhances glucose uptake in cells, improving the efficiency of glucose utilization throughout the body. The herb's ability to improve insulin sensitivity is particularly significant in maintaining healthy blood glucose levels. Furthermore, ginger plays a crucial role in regulating hepatic glucose metabolism, influencing how the liver processes and stores glucose. These effects are mediated in part through the modulation of AMPK pathway activation, a cellular energy sensor that regulates metabolism.

4.6. Immunomodulatory Effects

4.6.1. Cellular Immunity

The bioactive compounds found in ginger, with particular emphasis on gingerols and shogaols, demonstrate significant capabilities in modulating immune cell function through various mechanisms. These compounds effectively regulate T-cell differentiation and activation, playing a crucial role in adaptive immunity. They also modify dendritic cell maturation, which is essential for initiating immune responses. Furthermore, ginger compounds demonstrate control over macrophage polarization, influencing inflammatory responses, and enhance natural killer cell activity, which is crucial for innate immunity [17].

4.6.2. Inflammatory Mediators

Ginger compounds exhibit remarkable influence over cytokine profiles through multiple pathways. They effectively reduce the production of pro-inflammatory cytokines, helping to maintain immune system balance. The compounds also modulate chemokine expression, influencing immune cell recruitment and trafficking. Additionally, they regulate the expression of adhesion molecules and control inflammatory enzyme systems, contributing to their comprehensive immunomodulatory effects [18].

4.7. Antineoplastic Properties

4.7.1. Cancer Cell Growth Inhibition

Ginger demonstrates significant anticancer potential through multiple sophisticated mechanisms. It effectively induces cell cycle arrest in cancer cells, preventing their proliferation. The compounds in ginger activate apoptotic pathways, promoting programmed cell death in cancer cells. Furthermore, they exhibit potent angiogenesis inhibition properties, limiting blood vessel formation that supports tumor growth. The prevention of metastasis through various molecular pathways adds to ginger's comprehensive anticancer effects [19].

4.7.2. Chemotherapy

The usage of ginger in cancer therapy has shown good results through various beneficial effects. It significantly reduces chemotherapy-related side effects, improving patient tolerance to treatment. The compounds enhance the effectiveness of chemotherapeutic drugs, potentially improving treatment outcomes. Patients experience improved quality of life during treatment, and there is a notable reduction in treatment-related complications [20].

4.8. Effects on Reproductive System

4.8.1. Male Fertility

Ginger exhibits significant positive effects on male reproductive function through multiple mechanisms. It improves various sperm parameters, including count, motility, and morphology. The herb enhances testosterone production, supporting male reproductive health. It provides protection against oxidative stress in reproductive tissues and effectively modulates reproductive hormone levels, contributing to overall fertility enhancement [21].

4.8.2. Hormonal Balance

The influence of ginger on reproductive endocrinology is comprehensive and multi-faceted. It demonstrates effectiveness in gonadotropin regulation, maintaining proper hormone balance. The herb modulates steroidogenic enzymes, crucial for hormone synthesis. Additionally, it enhances Leydig cell function, important for testosterone production, and provides support to the hypothalamic-pituitary-gonadal axis, maintaining reproductive system homeostasis.

4.9. Neuroprotective Properties

4.9.1. Cognitive Function

Ginger's impact on neurological health encompasses various beneficial effects on cognitive function. It demonstrates significant capabilities in memory enhancement, improving both short-term and long-term recall. The herb contributes to cognitive performance improvement across various domains. It effectively regulates neurotransmitter systems and promotes neuroplasticity, supporting overall brain health and function [22].

4.9.2. Neurodegenerative Protection

The neuroprotective properties of ginger are manifested through multiple mechanisms. It significantly reduces oxidative stress in neural tissues, protecting against free radical damage. The herb effectively suppresses neuroinflammation, a key factor in neurodegenerative conditions. It provides protection to the blood-brain barrier, maintaining brain homeostasis, and modulates neurotransmitter systems, supporting overall neurological health and function

5. Therapeutic Applications

5.1. Inflammatory Conditions

Ginger has shown remarkable efficacy in managing various inflammatory conditions through its potent anti-inflammatory properties. In osteoarthritis management, ginger has shown significant benefits in reducing joint pain and improving mobility, making it a valuable complementary treatment option. For patients with rheumatoid arthritis, the herb's ability to modulate immune responses and reduce inflammation has proven beneficial in managing symptoms and improving quality of life. In the treatment of inflammatory bowel diseases, ginger's gastroprotective and anti-inflammatory properties offer relief from symptoms and help maintain remission. The herb also shows promise in addressing systemic inflammation, which is increasingly recognized as a underlying factor in many chronic diseases [23].

Table 2. Therapeutic Applications of Ginger

Condition	Study Type	Dosage Range	Findings	Reference
Chemotherapy-induced nausea	RCT	0.5-1.5g/day	Significant reduction in acute nausea ($p<0.05$)	Ryan et al., 2012 [20]
Osteoarthritis	Meta-analysis	500-1000mg/day	Reduced pain and disability scores	Bartels et al., 2015 [23]
Type 2 Diabetes	RCT	2g/day	Improved fasting blood glucose and HbA1c	Rahmani et al., 2014 [24]
Obesity	Systematic Review	1-3g/day	Significant reduction in body weight	Maharlouei et al., 2019 [25]

5.2. Gastrointestinal Disorders

In the treatment of functional dyspepsia, ginger helps alleviate symptoms such as bloating, early satiety, and upper abdominal discomfort through its prokinetic and anti-inflammatory effects. For patients with gastric ulcers, the herb's gastroprotective properties help in healing and preventing ulcer formation while providing relief from associated symptoms. In cases of intestinal motility disorders, ginger's ability to enhance gastric emptying and regulate intestinal movement makes it an effective therapeutic agent. The herb's well-established antiemetic properties make it particularly valuable in treating various forms of nausea and vomiting, including those associated with pregnancy, chemotherapy, and post-operative recovery.

5.3. Metabolic Disorders

Clinical applications of ginger in metabolic health encompass several significant areas of intervention. In Type 2 diabetes management, ginger has shown promise in improving insulin sensitivity and glucose regulation, helping to maintain optimal blood sugar levels. For obesity treatment, the herb's thermogenic and metabolic-enhancing properties contribute to weight management efforts, while also reducing inflammation in adipose tissue. In dyslipidemia control, ginger helps regulate lipid profiles, reducing

harmful cholesterol levels and improving cardiovascular health markers. The herb's comprehensive effects make it particularly valuable in metabolic syndrome intervention, addressing multiple aspects of this complex condition simultaneously [24].

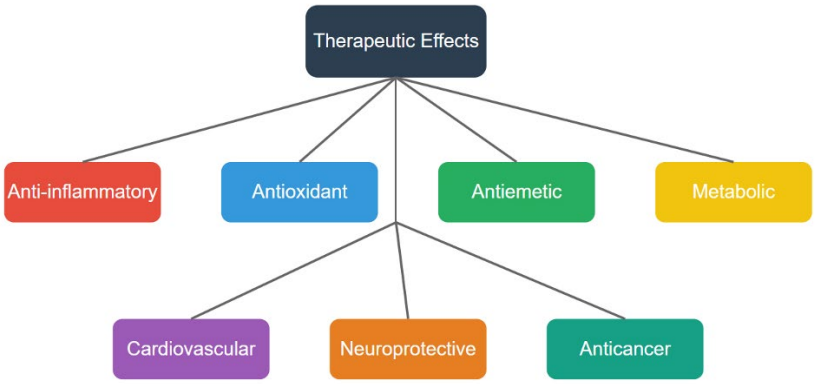

Figure 2. Therapeutic effects of Ginger

6. Formulations with ginger

6.1.1. Drug Delivery Systems

Nanoencapsulation techniques have been developed to enhance the bioavailability and stability of ginger's active compounds, improving their therapeutic efficacy. Liposomal formulations provide enhanced cellular uptake and targeted delivery of bioactive components. Controlled-release systems ensure sustained therapeutic effects over extended periods, optimizing treatment outcomes. Bioenhanced preparations incorporate various technological advances to improve the absorption and utilization of ginger's active compounds [25].

6.1.2. Combination Therapies

The integration of ginger with conventional treatments has led to innovative therapeutic approaches. Adjuvant therapy protocols have been developed to enhance the effectiveness of standard treatments while reducing side effects. Synergistic formulations combine ginger with other therapeutic agents to achieve enhanced therapeutic outcomes. Complementary medicine approaches incorporate ginger into holistic treatment strategies, while enhanced bioavailability systems optimize the delivery and effectiveness of combined therapeutic agents.

7. Pharmacokinetics and bioavailability

7.1. Absorption and Distribution

The bioactive compounds in ginger demonstrate complex and varying pharmacokinetic profiles, each with distinct characteristics affecting their therapeutic potential. Gingerols, while showing moderate oral bioavailability, are efficiently absorbed in the gastrointestinal tract. Shogaols demonstrate enhanced tissue distribution capabilities, allowing them to reach various target organs effectively. Paradols exhibit significant plasma protein binding, which influences their distribution and duration of action. The essential oils in ginger show rapid absorption kinetics, contributing to their quick onset of therapeutic effects [26].

Table 3. Pharmacokinetic Parameters of Major Ginger Compounds

Parameter	6-Gingerol*	6-Shogaol*	8-Gingerol*	10-Gingerol*
Bioavailability (%)	19.3 ± 3.5	25.6 ± 4.2	16.4 ± 2.8	14.2 ± 3.1
Tmax (h)	1.2 ± 0.3	1.0 ± 0.2	1.5 ± 0.4	1.8 ± 0.5
Half-life (h)	2.1 ± 0.4	2.8 ± 0.5	2.4 ± 0.6	2.7 ± 0.7
Plasma protein binding (%)	92.3 ± 2.1	95.1 ± 1.8	93.7 ± 2.4	94.2 ± 2.2

*Values are presented as mean ± SD based on data from Zick et al., 2008. [26]

7.2. Metabolism and Elimination

The metabolic processing of ginger compounds involves several sophisticated pathways. Phase I oxidation reactions modify the chemical structure of bioactive compounds, preparing them for further processing. Phase II conjugation processes facilitate the formation of more water-soluble compounds for elimination. The compounds undergo enterohepatic circulation, which can prolong their presence in the body and enhance their therapeutic effects. Renal elimination patterns vary among different compounds, influencing their duration of action and overall therapeutic efficacy.

8. Safety and Toxicology

8.1. Safety Profile

The herb demonstrates minimal adverse effects even with long-term consumption, making it suitable for sustained therapeutic use. Its wide therapeutic window provides flexibility in dosing while maintaining safety, allowing for individualized treatment approaches. The low toxicity profile of ginger has been well-established through numerous studies and centuries of traditional use. The herb's good tolerability across diverse populations makes it a favorable option in various therapeutic contexts [27].

8.2. Special Populations

Safety considerations for specific populations require careful attention and individualized approaches. For pregnant women, while ginger is generally considered safe for managing morning sickness, dosage and duration of use should be monitored carefully. Elderly individuals may require special consideration due to potential interactions with medications and age-related physiological changes. In pediatric patients, age-appropriate dosing and formulations need to be considered to ensure safety and effectiveness. Patients with comorbidities require particular attention to potential interactions with existing conditions and concurrent medications.

8.3. Drug Interactions

8.3.1. Pharmacodynamic Interactions

Important considerations regarding drug interactions focus on several key medication categories. With anticoagulant medications, ginger's natural blood-thinning properties necessitate careful monitoring to prevent excessive anticoagulation. When used alongside antidiabetic drugs, ginger's glucose-lowering effects should be considered to avoid potential hypoglycemia. Interactions with antihypertensive agents require attention due to ginger's effects on blood pressure regulation. The herb's antiplatelet properties warrant careful consideration when used in conjunction with antiplatelet medications to prevent excessive bleeding risk [28].

8.3.2. Pharmacokinetic Interactions

The influence of ginger on drug processing in the body encompasses several important mechanisms. Its effects on drug metabolism enzymes, particularly cytochrome P450 enzymes, can alter the processing of various medications. The herb's interaction with transport proteins may affect the movement of drugs across cellular membranes, potentially altering their effectiveness. Ginger can influence absorption mechanisms of other medications, either enhancing or inhibiting their uptake. Its effects on elimination pathways may alter the clearance rates of concurrent medications, potentially affecting their therapeutic efficacy and safety profiles.

9. Quality Control

9.1. Quality Parameters

Quality control measures for ginger products are comprehensive and essential for ensuring therapeutic efficacy and safety. Phytochemical profiling involves detailed analysis of the chemical constituents present in ginger preparations, including the identification and characterization of key bioactive compounds. This process ensures consistency in product composition and helps maintain therapeutic effectiveness. Bioactive compound quantification provides precise measurements of active ingredients such as gingerols, shogaols, and related compounds, ensuring that products meet specified potency requirements. Contamination assessment involves rigorous testing for potential contaminants including heavy metals, pesticides, microorganisms, and other unwanted substances that could compromise product safety. Stability evaluation encompasses monitoring the product's chemical and physical stability over time, including shelf-life determination and storage condition requirements [29].

9.2. Standardization Methods

The implementation of standardization methods ensures consistent quality and efficacy of ginger products across different batches and manufacturers. Chemical marker analysis involves the identification and measurement of specific compounds that serve as quality indicators, providing a reliable means of product standardization. This process helps ensure batch-to-batch consistency and product reliability. Biological standardization encompasses various bioassays and activity tests to confirm the therapeutic potency of ginger preparations, ensuring that products meet established efficacy standards. Process standardization involves the development

and implementation of detailed protocols for all aspects of production, from raw material selection to final product manufacturing, ensuring consistency in product quality. Quality assurance protocols integrate all aspects of quality control and standardization into a comprehensive system that monitors and maintains product quality throughout the manufacturing process, from raw material sourcing to final product release [30].

10. Conclusion

Ginger undoubtedly remains a significant medicinal plant with extensive therapeutic potential in modern healthcare. Scientific evidence supports its traditional applications while showing novel therapeutic possibilities. The different pharmacological activities of its bioactive compounds, particularly in inflammation, metabolism, and cancer, position it as a valuable resource in medicine. Recent progress in delivery systems and formulation methods have enhanced its therapeutic utility. Although substantial evidence supports its safety and efficacy, modern research continues to explore its new applications and mechanisms of action. The usage of ginger in modern healthcare requires continued investigation into standardization, bioavailability improvement, and clinical protocol development.

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