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Review Article

Phytochemical composition, health benefits, and potential food applications of ginger (*Zingiber officinale*)

Ali-Y Naoom[1], Zina-Abdulhussein Jawad[1], Ameena-N Seewan[1], Abbas-K Abbas[2], Raghda-A El-Sayed[3], Fatma-M El-Demerdash[3] (✉)

[1] *Department of Science, College of Basic Education, Al Muthanna University, Al-Muthanna* 66001, *Iraq*
[2] *Muthana Agriculture Directorate, Ministry of Agriculture, Al-Muthana* 66001, *Iraq*
[3] *Department of Environmental Studies, Institute of Graduate Studies and Research, Alexandria University, Alexandria* 21526, *Egypt*

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Abstract: Ginger, scientifically known as *Zingiber officinale* (*Z. officinale*), is a plant traditionally used in medicine to combat various ailments due to its diverse qualities, including antibacterial, antioxidant, anti-inflammatory, and anticoagulant effects. The zone of inhibition was evaluated by comparing it with various conventional antibiotics. *Z. officinale* is a medicinal herb that is frequently utilized in the production of culinary and pharmaceutical items. Its exact chemical composition and valuable active components have been thoroughly researched. This review concisely summarizes the pharmacological potential of this highly effective chemo-preventive medication. Our research also examined the therapeutic benefits of ginger and its components due to their potent antioxidant activities. Consuming these substances may potentially mitigate or postpone the advancement of associated illnesses, such as cancer, diabetes, and obesity, by influencing genetic and metabolic processes. The revised data could clarify the correlation between extraction techniques, components, and biological expressions.

Keywords: *Zingiber officinale*; phytochemical composition; health benefits; food applications

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1 Introduction

Natural products serve as the primary and crucial reservoir for pharmaceuticals and the process of discovering new medications. According to the World Health Organization (WHO), approximately 65% of the global population primarily relies on natural products derived from plants for their healthcare systems. The majority of these individuals are from developing countries. The remaining 35% are mostly from developed countries, where natural products are indirectly used to maintain good health. Spices are significant botanical substances that have been utilized since ancient times and continue to be valued now. Spices are not exclusively limited to culinary use. Flavorings are not only used for taste but also for food preservation and colorants. They help prolong the shelf-life of food and prevent it from spoiling[1].

Food-borne diseases are commonly treated with medications that are often recommended in traditional medicine. Antibiotics, which were highly effective in treating bacterial infections in the early 1900s, are now facing decreased efficacy due to the gradual development of resistance by bacterial cells over several decades. Unfortunately, the human host remains unaware of the emerging catastrophe of antibiotic resistance. Medicinal plants have the potential to serve as a promising alternative to these ineffective antibiotics. This review intends to evaluate one of the valuable herbal alternatives (*Zingiber officinale*; *Z. officinale*) and present its effects by evaluating recently released records, and demonstrating the significance of carried legacy from ancient times[2].

Ginger, scientifically known as *Z. officinale* and classified under the *Zingiberaceae* family, has been extensively utilized as a culinary ingredient in a diverse range of global cuisines and drinks. Ginger has been utilized as a traditional remedy in Southeast Asia for treating various ailments such as stomach issues, sore throats, coughs, fevers, and more. Ginger's biological action stems from its volatile and non-volatile components. The essential oils found in ginger consist of sesquiterpenes and monoterpenoids, which contribute to its characteristic scent. On the other hand, ginger contains non-volatile components that contribute to its strong and spicy taste. These components include gingerol, shogaol, zingerone, and paradol. Gingerol is the primary constituent found in fresh ginger. However, in ginger-based goods, gingerol undergoes conversion into shogaol, zingerone, and paradol[3].

2 Extraction method

Secondary metabolites are organic compounds produced by plants that possess bioactive properties, such as phenolics, flavonoids, and terpenoids. Various chemical and physical factors, including light, temperature, medium pH, aeration, and cell

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Address correspondence to Fatma-M El-Demerdash, eldemerdashf@alexu.edu.eg

density, have been shown to affect secondary metabolism in plant cell cultures. For instance, varying light intensities can alter the synthesis of phenolic and flavonoid compounds in ginger[4, 5].

Phenolic compounds are a major class of secondary metabolites found in plants and are commonly present in foods and nutraceuticals. These phytochemicals exhibit diverse biological activities, including antioxidant properties, anti-inflammatory effects, enzyme activity modulation, and gene expression regulation. The total polyphenolic content in the ginger extract has been measured at 181.41 mg/g, while the flavonoid content was found to be 14.15 mg/g[6].

Flavonoids are crucial in plant biochemistry, contributing significantly to plant physiology by functioning as antioxidants, enzyme inhibitors, pigments, and light filters. HPLC analysis showed that the production of flavonoids like quercetin, catechin, epicatechin, and naringenin increased under low-light conditions. However, reduced light intensity also lowered the rate of photosynthesis, leading to a decrease in soluble carbohydrates and plant biomass in both Halia Bentong and Halia Bara varieties[5].

Drying of ginger rhizome should be done below 70 °C for better quality dried products. For glycoside species, a maximum temperature of 100 °C is recommended, for mucilage species 65 °C, and for essential oil species 35 to 45 °C[7].

A study was conducted to compare the decoction and maceration methods using water and ethanol as solvents for extracting flavonoid and phenolic content. The ginger was oven-dried at 50 °C and macerated in ethanol (10 g in 100 mL) for three periods of 24 h and once for 48 h. Another sample was decocted in distilled water for 24 and 48 h. Both extracts were then rotavaporated. The ethanol extract was found to be more active, despite having lower total flavonoid and phenolic content compared to the water extract, which contained higher amounts of both. Traditionally, compounds like 6-gingerol and 6-shogaol are extracted through reflux or Soxhlet methods, but prolonged high-temperature extraction may degrade these compounds and result in high energy consumption. Under acidic conditions and high temperatures, 6-gingerol can convert to 6-shogaol. The optimal extraction conditions were found to be 76.9 °C for 3.4 h. Optimizing the extraction process can significantly enhance the pharmaceutical quality of ginger[8].

3 Ginger characterization

3.1 Characterization of the morphology and anatomy

Ginger (Fig. 1) has been found to exhibit variability in terms of yield, qualitative attributes, and rhizome features. Primitive types, which are outdated cultivars, typically have small rhizomes and produce low yields. However, the cultivars and improved variants have larger, more visually appealing rhizomes and higher yields, although the quality may vary. However, the productivity and quality of ginger may vary with genetic variation, soil composition, geographic location, seasonal variation, cultivation practices, and climatic conditions[9]. Ginger (*Z. officinale*) is anatomically distinct from *Zingiber zerumbet* (*Z. zerumbet*), *Zingiber roseum* (*Z. roseum*), and *Zingiber macrostachyum* (*Z. macrostachyum*) due to its lack of periderm, short-lived effective cambium, and the inclusion of xylem vessels with scalariform thickening in the rhizome[10].

The immune function of the body is crucial for the prevention of diseases, the recovery from diseases, and the reduction of the risk of both infectious and chronic diseases. Enhancing the body's immune system can be achieved by consuming well-balanced nutritional foods enriched with vitamins, minerals, and bioactive chemicals. Herbal plants possess bioactive chemicals that can enhance the immune system. Furthermore, herbal plants possess medicinal properties and the capacity to exhibit antioxidant activity, thereby inhibiting free radicals and mitigating oxidative stress and inflammation within the body[11].

Immunomodulators are agents that assist in controlling the functioning of the immune system. Immunomodulators exist in both natural and external forms, and their mode of action frequently relies on their antioxidant capabilities. Several natural plant antioxidants, such as alkaloids, flavonoids, flavones, flavonols[12], flavanols, isoflavones, quinones, and terpenoids, have been demonstrated to possess immunomodulatory activities. Antioxidant-derived immunomodulators assist in preserving health by controlling the equilibrium between oxidants and antioxidants and regulating the immunological response. Antioxidants function through the direct elimination of reactive oxygen-nitrogen species and the indirect enhancement of the body's antioxidant balance. Several bioactive chemicals found in various plants have been extensively studied for their ability to modulate the immune system[13].

Several researchers have investigated the biological activity of ginger, the active components responsible for it, and their mechanism of action. Research conducted in laboratory settings (*in vitro*) and living organisms (*in vivo*) has shown that ginger crude extract possesses several biological properties, including antioxidant, anti-inflammatory, antibacterial, antiviral, and anticancer effects. Kausar *et al.* conducted a study on ginger's medicinal properties, including its antioxidant, anti-nausea,

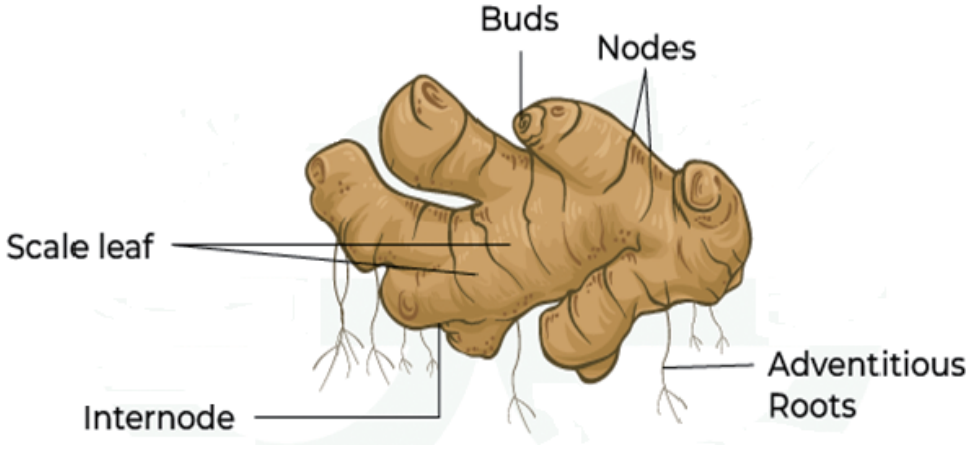


Figure 1 Ginger rhizome diagram.

anti-inflammatory, anti-cancer, cardiovascular, and anti-diabetic effects[14].

3.2 Ginger's chemical composition

Phytochemical analyses have demonstrated that ginger rhizome harbors a diverse array of bioactive chemicals as illustrated in Fig. 2[15]. The concentration of these compounds can vary depending on factors such as growing circumstances, temperature, harvesting, and the procedure used for extracting the ginger rhizome. The delightful scent of ginger is attributed to around 70 components found in the volatile oil released after steam distillation, including mono and sesquiterpenes such as camphene and β-phellandrene[12].

4 Pharmacological effects

The quantity and the quality of ginger vary based on the genotypes. Additionally, the plant has been found to possess a wide range of beneficial activities, including antimicrobial, anticonvulsant, analgesic, anti-inflammatory, antiulcer, gastric antisecretory, antidiabetic, nephroprotective, hepatoprotective, antitumor, anticancer, antispasmodic, antithrombotic, hypocholesterolemic, antiallergic, antiserotonergic, anticholinergic, antioxidant, larvicidal, and immunomodulatory properties. The various aspects to keep in mind include the types, locations, seasons, cultural practices, and climatic conditions[16].

4.1 Potential for hypoglycemia

The hypoglycemic potential of ginger was examined in diabetic rats. The study demonstrated that ginger effectively lowers glucose levels in the blood, as well as levels of triacylglycerol and cholesterol in diabetic rats. Therefore, the study concluded that raw ginger has hypoglycemic, hypolipidemic, and hypocholesterolemic properties[17].

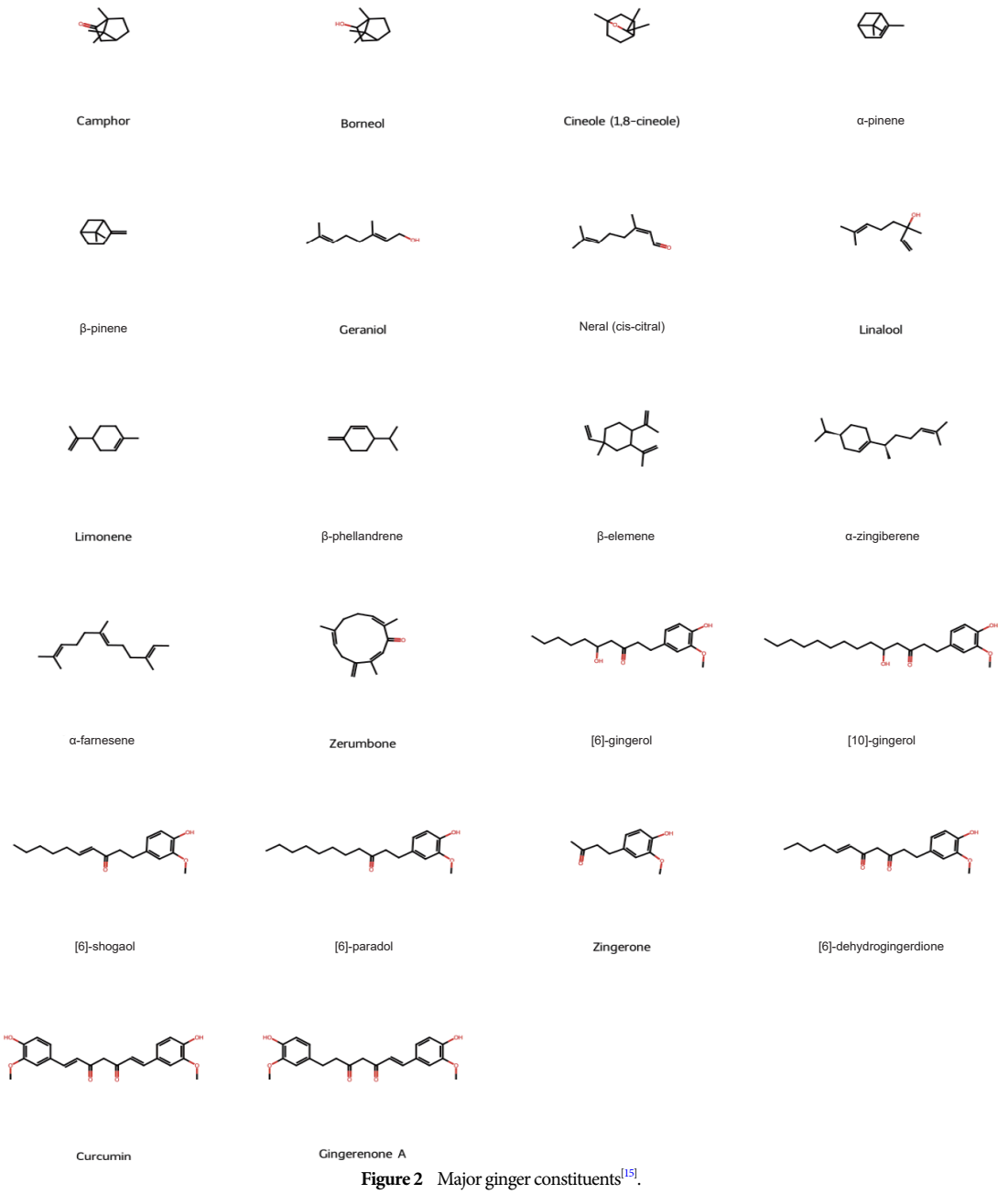


Figure 2 Major ginger constituents[15].

4.2 Antimicrobial effects

Ginger exhibits significant antibacterial and antifungal effects. The active chemicals found in ginger have been shown to inhibit the growth of many bacteria, including *Escherichia coli* (*E. coli*), *Proteus* spp., *Staphylococci*, *Streptococci*, and *Salmonella*, in laboratory studies conducted on colon samples. Colon bacteria produce antimicrobial properties and cause flatulence through the fermentation of undigested carbohydrates. This flatulence can be managed by consuming ginger. Ginger has antifungal properties that suppress the growth of *Aspergillus*, a fungus known for producing carcinogenic aflatoxin. The ginger juice extract exhibited inhibitory effects against *Saccharomyces cerevisiae* (*S. cerevisiae*) (10%), *Aspergillus niger* (*A. niger*) (4%), *Mycoderma* spp. (12%), *and Lactobacillus acidophilus (L. acidophilus)* (14%) at room temperature[18].

4.3 Impact on cardiovascular health

Ginger exerts a beneficial influence on the cardiovascular system. Blood coagulation leads to the formation of plaque or thrombosis, which can result in various cardiovascular diseases. However, ginger prevents heart diseases by reducing blood coagulation and also helps in opening the blockage in the blood vessels, thereby reducing blood pressure and peripheral vascular resistance. Furthermore, it is crucial to lower elevated levels of cholesterol to promote heart health. Ginger is recognized as a potent cardiac tonic in Ayurvedic medicine[19]. *In vitro* studies have demonstrated that the aqueous extract of ginger can effectively inhibit platelet aggregation generated by adenosine diphosphate (ADP), adrenaline, collagen, and arachidonic acid. This suggests that ginger may have a positive impact on cardiovascular health. Ginger has been reported to impede the production of thromboxane, a compound involved in blood clotting. The most prevalent component of ginger, 6-gingerol, has been shown to have antiplatelet activity, mostly *via* inhibiting the creation of thromboxane. Ginger also inhibits the production of prostacyclin in rat aorta[20].

4.4 Antioxidant effects

Phenolic molecules are the primary contributors to antioxidant action in plants. Ginger possesses antioxidant properties due to its high polyphenol concentration. Antioxidants have a crucial role in preventing specific diseases and slowing down the aging process. A study conducted on over 120 plant foods found that ginger was rated first among the top five sources of antioxidants. Additionally, ginger stimulates the formation of antioxidants in the body. Ginger exhibits antioxidant properties, which help to neutralize free radicals[21].

The antioxidant activity of ginger has been assessed *in vitro*. The quantity of phenolic compounds in dried ginger was 5.2-, 1.1-, and 2.4-fold higher than in fresh, stir-fried, and carbonized ginger, respectively, indicating that it had the highest antioxidant activity, using the ferric-reducing antioxidant power (FRAP), 2,2-diphenyl-1-picrylhydrazyl (DPPH), and 2,2-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) techniques, the order of the gingers' relative antioxidant activity was dried ginger, stir-fried ginger, carbonized ginger, and fresh ginger. Their polyphenolic contents were mostly linked to this. Because fresh ginger has a higher moisture content than dried ginger, heating fresh ginger produced dried ginger with higher antioxidant activity.

Nevertheless, because processing could convert gingerols into shogaols, the antioxidant activity was reduced when dried ginger was cooked further to produce stir-fried and carbonized ginger[22]. Furthermore, data from FRAP, oxygen radical absorbance capacity, and cellular antioxidant activity experiments indicated that a portion of the dried ginger powder rich in polyphenols exhibited strong antioxidant activity[23]. Moreover, ginger's antioxidant activity may be impacted by the type of extraction solvent used. Ginger extracts in ethanolic and aqueous forms demonstrated strong free radical scavenging and chelating properties, as well as high Trolox-equivalent antioxidant capacity and ferric-reducing ability[24].

Further, ginger extracts in ethanolic, methanolic, ethyl acetate, hexane, and water successively inhibited 71%, 76%, 67%, 67%, and 43% of human low-density lipoprotein (LDL) oxidation triggered by Cu^{2+}[25]. Based on the results of a xanthine/xanthine oxidase system, extracts of ethyl acetate and water were found to have greater antioxidant qualities than extracts of ethanol, diethyl ether, and *n*-butanol[26].

Numerous studies have demonstrated the effectiveness of ginger in preventing oxidative stress. Cell models were used to study the fundamental mechanisms of antioxidant activity[27, 28]. Interleukin-1β (IL-1β) caused oxidative stress in human chondrocyte cells, and ginger extract had antioxidant properties. It decreased the production of reactive oxygen species (ROS) and lipid peroxidation and increased the expression of numerous antioxidant enzymes[29]. Additionally, in human fibrosarcoma cells with H_2O_2-induced oxidative stress, ginger extract may lessen the generation of ROS[30]. Ginger extract reduced the amount of malondialdehyde (MDA), a substance linked to lipid peroxidation, in homogenates of stressed rat hearts[28]. The nuclear factor erythroid 2-related factor 2 (Nrf2) signaling pathway is responsible for the antioxidant activity of ginger and its bioactive components, including 6-shogaol (Fig. 3)[31].

6-Shogaol upregulated the expression of Nrf2 target genes, including heme oxygenase-1 (HO-1), metallothionein 1 (MT1), aldo-keto reductase family 1 member B10 (AKR1B10), ferritin light chain (FTL), and glutamyltransferase-like activity 4 (GGTLA4), and increased intracellular glutathione/glutathione disulfide (GSH/GSSG) in human colon cancer cells. Additionally, 6-shogaol increased the expression of genes related to the manufacture of GSH, including the glutamate-cysteine ligase modifier subunit (GCLM) and catalytic subunit (GCLC) of the enzyme. Subsequent investigation showed that cysteine residues in Kelch-like ECH-associated protein 1 (Keap1) were alkylated by 6-shogaol and its metabolite, activating Nrf2[32]. Additionally, in foreskin fibroblast cells, ginger phenylpropanoids increased Nrf2 activity, glutathione S-transferase P1 (GSTP1) levels, and the downstream effector of the Nrf2 antioxidant response element (ARE)[33].

The effects of ginger oleoresin on ionizing radiation-induced damage were studied using a human mesenchymal stem cell model. By moving Nrf2 to the cell nucleus and triggering the expression of the *HO-1* and *NQO1* (nicotinamide adenine dinucleotide phosphate (NADPH) quinone dehydrogenase 1) genes, oleoresin therapy may reduce the amount of ROS[27].

4.5 Impact on cancer treatment

Ginger components are hypothesized to be chemopreventive dietary agents because they inhibit the activities of lypoxygenase (LO) and cyclooxygenase (CO), cause apoptosis, and have antitumorogenic characteristics. Prostate cancer cells are triggered by 5-LO enzymes, which ginger inhibits[34]. Without the 5-LO enzyme, prostate cancer cells die in 1 to 2 h. Ginger fights

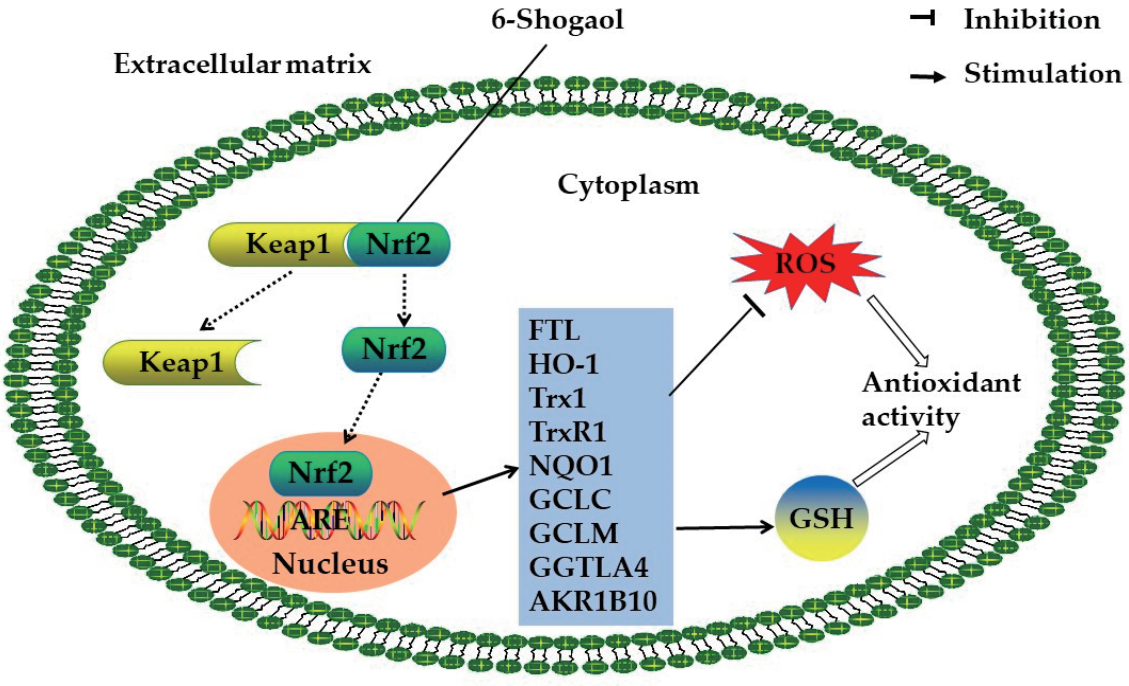


Figure 3 The potential mechanism for the antioxidant action of 6-shogoal: 6-shogoal leads to the translocation of Nrf2 into the nucleus and increases the expression of Nrf2 target genes by modifying Keap1 and preventing Nrf2 from proteasomal degradation. Thus, the level of GSH increases and the level of ROS decreases. Nrf2, nuclear factor erythroid 2-related factor 2; Keap1, Kelch-like ECH-associated protein 1; NQO1, nicotinamide adenine dinucleotide phosphate (NADPH) quinone dehydrogenase 1; HO-1, heme oxygenase-1; GCLC, glutamate-cysteine ligase catalytic subunit; GCLM, glutamate-cysteine ligase modifier subunit; Trx1, thioredoxin 1; TrxR1, thioredoxin reductase 1; AKR1B10, Aldo-keto reductase family 1 member B10; FTL, ferritin light chain; GGTLA4, -glutamyltransferase-like activity 4; ROS, reactive oxygen species; GSH, glutathione; ARE, antioxidant response element[31].

leukemia, skin, kidney, lung, and pancreatic cancer cells. Several components, including 6-gingerol and 6-paradol, as well as other compounds such as zingerone and shagaols, are thought to contribute to ginger's anticancer activity. As a result, taking it for cancer treatment is safe. Gingerol is a strong anti-tumor agent in leukemia cells, inhibits pancreatic cell proliferation, and aids in the prevention of cancer-related constipation[35].

4.6 The use of plants as antiemetic agents

Ginger contains non-volatile phytochemicals that have a strong smell and taste. These phytochemicals include gingerols, shogaols, paradols, and zingerone. Fresh ginger contains gingerols, which are a group of chemical compounds that vary in their alkyl chain length. These compounds are classified as [3-6]-, [8]-, [10]-, and [12]-gingerols, depending on the number of carbon atoms in their side-chain. The principal active components of fresh ginger are gingerols with side-chains containing 7–10, 12, 14, or 16 carbon atoms. The molecule 6-gingerol is the most prevalent and well-studied ginger phytochemical among the gingerols[36].

Gingerols are susceptible to thermal instability due to the presence of a β-hydroxy keto group, which causes them to easily dehydrate and generate shogaols. The magnitude of this transformation is expected to have a substantial influence on the therapeutic advantages of ginger, as the two categories of substances differ in their capacity to be absorbed by the body, the way they are processed in the body, and their effects on the body's functions. Shogaols can undergo hydrogenation to be transformed into paradols, which share similarities with gingerol[37]. Gingerol and shogaol are the primary pharmacologically active compounds in ginger, and their relative amounts, together with paradols, contribute to its principal pharmacological activity. In India, ginger has been utilized as a medicinal remedy since Vedic times and is referred to be "maha aushadhi," which translates to great medicine. It plays a crucial role in numerous medicinal preparations within Ayurveda, the ancient Indian medical system. Ginger is documented in numerous ancient medical systems as having multiple therapeutic properties. Studies have demonstrated that ginger possesses antibacterial, antischistosomal, anti-inflammatory (Table 1)[38], antipyretic, antioxidant, hypoglycemic, hepatoprotective, diuretic, and hypocholesterolemic effects.

4.7 Anti-inflammatory activity and mechanism of ginger action

Morvaridzadeh *et al.*[39] conducted a systematic review and meta-analysis to assess the anti-inflammatory effects of ginger supplementation on C-reactive protein (CRP), high sensitivity C-reactive protein (hs-CRP), tumour necrosis factor-alpha (TNF-α), soluble intercellular adhesion molecule (sICAM), and interleukin-6 (IL-6) levels in randomized controlled trials. Increased levels of IL-6, TNF-α, and CRP are linked to an increased risk of inflammation. Immune system components such nuclear factor- kappa-B (NF-κB) and peroxisome proliferator-activated receptor-gamma (PPAR-γ) are overexpressed, leading to elevated indicators[40].

As a result, suppressing the inflammatory response is critical in the treatment of certain chronic conditions, such as cardiovascular disease. Ginger supplementation significantly reduced circulation levels of CRP, hs-CRP, and TNF-α. However, the meta-analysis found that ginger supplementation had no significant effect on IL-6 or sICAM levels[39].

Ginger has also been used as an adjuvant to chemotherapy to alleviate nausea and vomiting caused by chemotherapy, according to systematic reviews and meta-analyses. Ginger supplementation may help to alleviate chemotherapy-induced vomiting and fatigue;

Table 1 Anti-inflammatory activity and potential mechanisms of ginger[38]

Constituent	Study type	Subjects	Dose	Potential mechanisms
6-shogaol	*In vivo*	HCT-116 human colon cancer cells	20 μmol/mL	Increasing the intracellular GSH/GSSG ratio; decreasing the level of ROS; upregulating the expression of *AKR1B10*, *FTL*, *GGTLA4*, *HO-1*, *MT1*, *GCLC*, and *GCLM* genes
	In vivo	Wild-type and Nrf2−/− C57BL/6J mice	100 mg/kg	Upregulating the expression of *MT1*, *HO-1*, and *GCLC*
Ginger oleoresin	*In vivo*	Human mesenchymal stem cells	100 μg/mL	Reducing ROS production; inducing the translocation of Nrf2 to the cell nucleus; activating *HO-1* and *NQO1* gene expression
Ginger phenylpropanoids	*In vivo*	BJ foreskin fibroblasts	40 μg/mL	Increasing Nrf2 activity and the level of GSTP1
6-gingerol-rich fraction	*In vivo*	Female Wistar rats	50 and 100 mg/kg	Reducing the levels of H_2O_2 and MDA; increasing the activities of antioxidant enzymes and the level of GSH
	In vivo	Male Wistar albino rats	100 mg/kg	Reducing the level of MDA; preventing the depletion of catalase activity and GSH content
Ginger extract	*In vivo*	C28I2 human chondrocyte cells	5 and 25 μg/mL	Increasing the gene expression of antioxidant enzymes; reducing the content of ROS and lipid peroxidation
	In vivo	HT1080 human fibrosarcoma Cells	200 and 400 μg/mL	Reducing the generation of ROS
	In vivo	Rat heart homogenates	78–313 μg/mL	Decreasing the level of MDA

NO, nitric oxide; PGE2, prostaglandin E2; TNF-α, tumor necrosis factor α; GDNPs 2, nanoparticles derived from edible ginger.

however, due to clinical heterogeneity, this systematic review found no link between ginger supplementation and chemotherapy-induced nausea and vomiting-related outcomes[41].

4.8 Ginger importance in the treatment of motion sickness

Regarding the impact of ginger on motion sickness, research findings have been inconsistent. Ginger's ability to alleviate motion sickness may be attributed to its impact on the stomach as well as its ability to address the imbalance between the vestibular and oculomotor systems. Ginger juice has been found to have anti-motion sickness properties in animal experiments, potentially due to its effects on the central and others[42].

4.9 Ginger ability in the prevention of pregnancy-induced conditions, emesis and regurgitation

Ginger has been employed since ancient times as a herb possessing antiemetic effects for the management of nausea and vomiting in Chinese and Ayurvedic medicine. These results have been substantiated and bolstered by scientific investigation. Multiple studies have substantiated the positive effects of ginger in avoiding nausea and vomiting during pregnancy (NVP) without any adverse effects on pregnancy outcomes[43].

Anh *et al.*[44] conducted a groundbreaking study using a double-blind randomized crossover trial. Ginger (250 mg) was supplied to pregnant women with hyperemesis gravidarum (HG) for 4 days. Subsequently, a 2-day interval was observed before introducing the alternate drug for the duration of the second 4-day period. The scientists evaluated the severity and relief of symptoms before and after each menstrual cycle using two grading methodologies. The study revealed that 70.4% of the individuals exhibited a preference for ginger compared to the placebo.

4.10 Antimicrobial efficacy

Some extracts of dried and processed ginger were reported to have antibacterial activities against some Gram-positive and Gram-negative bacteria as evaluated using the disc diffusion method. Antibiotics were used as a positive control, and minimal inhibitive concentration (MIC) was determined. The extracts had MIC values ranging from 5–50 μg/mL, with the least active was against *E. coli* with a MIC value of 50 μg/mL. The organic extracts revealed higher antibacterial activities than aqueous extracts, and there were no significant differences between dried and processed gingers and among organic extracts gingers[45].

A further investigation was conducted to assess the antibacterial efficacy of freshly obtained, naturally derived, and commercially dried *Z. officinale* extracts against seven bacterial species often seen in local clinical settings. The agar disc diffusion method was employed for this purpose. The results suggest that *Z. officinale 's* chloroform and diethyl ether extracts showed a significant inhibitory zone against the investigated pathogens, except for *Pseudomonas aeruginosa* (*P. aeruginosa*) and *E. coli*. The *in vitro* antibacterial activity of the methanolic extract of *Z. officinale* was assessed using the agar diffusion method. The zone of inhibition was assessed by comparing it with different conventional antibiotics[46].

5 Side effects

In general, *Z. officinale* is considered safe for use. There is a slight risk of toxicity in normal doses, but some people may have indigestion. *Z. officinale* can also cause contact dermatitis in sensitive individuals. *Z. officinale* is reported to cause severe hyperkalemia in patients with cirrhosis. Use ginger with caution in people with liver disorders or liver disease who have been exposed before[47].

6 Toxicity

Acute toxicity studies with an oral single dose of *Z. officinale* rhizome (2,000 mg/kg and 2,500 mg/kg) were observed for 14 days on rats, and no death was found (LD_{50} > 2,000 mg/kg and LD_{50} > 2,500 mg/kg).[36] Sub-acute toxicity study with fine powder of *Z. officinale* rhizome (up to 2,000 mg/kg/day) was administered orally to male and female rats for 35 days and showed no toxic effect[48].

7 Dosage

Ginger doses generally are 1–4 g per day, taken in divided

doses[49]. To prevent motion sickness: 0.5 g, 2–4 times daily in adults and children more than 6 years, and for dyspepsia: 2–4 g daily, as powdered plant material or extracts[47,48].

8 Current and potential applications

There is an increasing demand for healthier and functional food products as consumers become more mindful of healthy lifestyles and daily nutritional intake. This rising interest in functional foods has expanded the exploration, characterization, and potential use of bioactive compounds and ingredients. Ginger, known for its rich bioactive content and functional properties, has been incorporated into various food products. This discussion will cover the different forms of ginger (powder, juice, extract, and essential oil) used in food applications, providing a comprehensive perspective on its utilization. Additionally, the impact of ginger on the sensory qualities of these food products will be explored.

8.1 Bakery Products

Numerous studies have explored the use of ginger as a potential additive in bakery products (Table 2). For example, adding ginger powder at a concentration of 2%–4% has been shown to enhance the texture, rheological properties, antioxidant activity, and mineral content of bread[50]. Balestra *et al.*[51] also developed a functional bread incorporating ginger, which demonstrated acceptable physicochemical and sensory qualities.

They found that up to 3% of ginger powder can be incorporated into the bread without compromising the rheological properties of the dough and bread. Another study also came up with similar findings over the functional, physicochemical, and sensory properties of bread fortified with ginger powder but with a different optimized level of ginger powder (1%) than the previous study[52]. Moreover, Almasodi[53] studied the addition of ginger powder in bread as well as in rusk. They concluded that the incorporation of up to 3% and 6% of ginger powder resulted in satisfactory hedonic and textural properties for bread and rusk, respectively. In another study, garlic and ginger powders at different concentrations were also incorporated in wheat bread. Besides functionality improvement, it also increased the shelf life of the bread from 5 days to 7 days at an ambient temperature[54]. Ginger and turmeric have inhibitory effects on the growth of Rhizopus stolonifer on bread, but ginger may impart unfavorable flavor characteristics to the bread[55].

The aforementioned studies mainly dealt with the addition of ginger to produce functional bread. However, in some parts of the world, distinct baking products exist wherein ginger is used as a dominant flavoring ingredient. For instance, gingerbread is a traditional bakery product in the Czech Republic, particularly in the town of Pardubice, where ginger is the prevalent flavor. It is produced in a variety of shapes, types, and textures ranging from a crispy biscuit to a soft cake[56,57]. Hence, ginger has been practiced as a flavor enhancer, solely or in combination, for a long time, but it is largely dependent on the nature of the food product, the form of the ginger to be incorporated, their mutual compatibility, and the sensorial preferences of the consumers.

Lee *et al.*[58] proposed that functional cookies could be made by incorporating 4% ginger powder, as this amount was found to provide overall acceptability without significantly affecting quality characteristics. Kaushal *et al.*[59] also studied the functional and sensory properties of cookies with ginger powder, finding that cookies supplemented with 12% ginger powder had superior functional and organoleptic qualities compared to the controls. In another study, Yang *et al.*[60] evaluated the impact of ginger on acrylamide levels in dough and biscuits. The addition of 1% ground ginger resulted in favorable structural and color characteristics, with a 6.2% reduction in acrylamide and acceptable sensory properties. While higher ginger concentrations further reduced acrylamide, they negatively impacted hedonic qualities. Gingerols were shown to reduce acrylamide content by inhibiting its formation, with the phenol hydroxyl group playing a key role. Kumari and Gupta[61] also used ginger powder and other functional plant ingredients to create value-added cookies, achieving acceptable sensory properties with 2.5% ginger powder.

The functional, nutritional, antioxidant, and sensorial properties of millet flour and ginger powder-formulated cookies were investigated by Marak *et al.*[62]. This study reported that ginger flour incorporation of up to 10% was found satisfactory for the textural and sensorial properties of cookies, and it also efficiently improved the functional and nutritional values of cookies with a potential lead towards shelf life extension. When cumin and ginger were utilized for the preparation of cookies, a minimal difference was observed in the dough development as compared to the control[63]. Both potential ingredients were integrated in concentrations of up to 5% in soft wheat cookies, but there was not any substantial effect on the end product. Keeping in view the acceptability and feasibility indicators, these concentrations were also recommended for commercial-scale production.

The antimicrobial effect of ginger was also evaluated through the addition of ginger powder to biscuits. Aerobic bacteria were decreased proportionally by increasing the amount of ginger powder in biscuits. Functional biscuits with significant activity against bacteria and mold could be produced with around a 2.5% addition of ginger powder without any compromise on the quality characteristics[64]. Adebayo-Oyetoro *et al.*[65] also prepared ginger spiced cookies with around a 3% addition of ginger powder.

Table 2 Some important studies on the application of ginger and its derivatives to bakery products[66]

Derivative	Product	Positive effect
Ginger powder	Wheat bread	↑Antioxidant activity; minerals; total phenolics; textural properties; shelf life; sensorial characteristics; ↓microbial growth
	Cookies	↑Antioxidants; phenolic contents; shelf life; ↓acrylamide content; microbial growth; ≈ sensorial characteristics
	Cake	↑Antioxidant activity; total phenolics, shelf life; sensorial properties; ↓ bacterial and fungal growth
Ginger juice	Wheat flour muffin	↑Total phenolics; antioxidants; sensorial characteristics; ≈ textural attributes
Ginger extract	Baked bars	↑Antioxidants; phenolic contents; antioxidant retention during storage; flavor and color; ≈ overall acceptability

↑ = Increased/Improved, ↓ = Lower/Decreased, ≈ = Negligible/Unchanged.

8.2 Dairy products

There is also considerable potential for innovation and improvement in the dairy sector, where ginger, an active ingredient, has also contributed. The supplementation of ginger powder (1%) has been displayed as a bovine yogurt product with an enhanced nutritional value, better quality characteristics, and ease in the production process[67].

Ginger powder is also formulated with dromedary milk to prepare and characterize a functional yogurt product. The resultant product showed very similar results to the previous study (bovine milk yogurt) with the recommendation of 1% ginger powder as an optimum supplementation extent. The water holding capacity, viability of the starter culture, and rate of pH reduction were increased, while the fermentation time and flow behavior were decreased, leading to an acceptable yogurt from dromedary milk[68]. Ethiopian cottage cheese, 'Ayib', was also treated with ginger and garlic powders to analyze their impacts on the chemical arrangement and sensorial characteristics of the product[69]. Ayib treated with garlic powder was described with better overall acceptability than ginger powder, and further investigations were suggested to explore the biochemical and microbial properties of both powders.

A novel approach was also attempted to evaluate the effects of ginger, cinnamon, and carob powders on spray-dried milk powders and their agglomerates[70]. Milk powder with added ginger powder relatively performed better in terms of solubility, hygroscopicity, flowability, and cohesiveness. The incorporation of these powders significantly reduced the solubility time of milk powders, while the water activities and moisture levels of the resultant products were also within adequate extents, feasible for the safe storage of these milk powders. In another investigation, an Indigenous sub-continental sweet dairy product, Peda, was also prepared, analyzed, and finally optimized (2%) utilizing ginger powder[71].

The inclusion of ginger powder into Peda not only increased the total solid, total sugar, and ash contents but also improved its shelf life by reducing the total plate count. Apart from ginger powder, the effect of ginger juice on the physicochemical and hedonic attributes of yogurt was also investigated at different concentrations. An inverse relationship was observed between the amount of ginger juice, the viability of the starter culture, and the hardness of the product. Based on the findings of this study and the sensorial characteristics of the product, the ginger juice addition at the rate of 4% (*v*/*v*) was regarded as the suitable concentration in yogurt production[72], while Allam *et al.*[73] reported that ginger juice (2%) incorporation into fermented milk products reduced the coagulation time and accelerated the syneresis process.

Jadhav *et al.*[74] formulated a functional milkshake product *via* the inclusion of ginger juice at four different concentrations from 2.5% to 10% (*v*/*v*). The increase in the ginger juice concentration was inversely proportional to the fat, protein, and total solid contents of the product. Considering the sensorial properties and other attributes, a 2.5% ginger juice addition in the milkshake was regarded as an optimum value. Gaur *et al.*[75] also successfully developed an herbal milk product by optimizing the concentrations of herbal ingredients such as ginger, turmeric, and tulsi (holy basil).

Several studies were also designed for the potential exploitation of ginger into an herbal ice cream product. Herbal ice cream could be manufactured employing 4% ginger juice (*w*/*w*) with a better hedonic response than all other treatments including the control. Ginger juice improved the product's resistance against melting but lowered the fat and total solid contents in the herbal ice cream[76]. Similar findings were also reported in another investigation[77]. The incorporation of ginger juice has a pertinent effect on the thermal properties but no substantial influence on the freezing characteristics of ice cream[78]. Mule *et al.*[79] efficiently employed ginger juice, aloe vera juice, and *L. acidophilus*-based probiotic culture to produce probiotic ice cream at the optimized levels of 3%, 6%, and 7% (*w*/*w*), respectively.

The fortification of ginger extract into fermented dairy products is another approach to bestow the favorable characteristics of ginger to the products. Ginger extract, at an 8% concentration of the low-fat yogurt formulation, not only boosted the phenolic contents and antioxidant activities but also played a vital role in the retention of these properties[80]. The addition of ginger extract also lowers the syneresis process in the yogurt. During the storage period, there was not any remarkable effect on the acidity, but the viscosity of the product was decreased with the incorporation of ginger extract.

In two other investigations, herbal yogurt was developed using ginger extract and evaluated for its antioxidant capacity and sensorial properties. Ginger was regarded as a better source of antioxidant properties than beetroot, while the herbal yogurt containing ginger extract (2%) and goat milk was characterized with the highest antioxidant activity than other milk sources (buffalo and cow). A sensorial analysis revealed that herbal yogurt augmented with ginger extract (1%) was superior in color and appearance, while garlic extract (0.2%) was responsible for a better taste and flavor[81,82].

Ginger extract in combination with gum Arabic has also been exploited in the manufacturing of a yogurt-based traditional Iranian drink, Doogh[83]. The symbiotic dairy product with maximal overall acceptability and advanced probiotic status was developed with a blend of ginger and gum Arabic at the concentrations of 0.25% and 0.5%, respectively. In another attempt to produce symbiotic labneh through the efficient utilization of ginger and probiotics, an effective inhibitory effect on some food-borne pathogens was detected along with an enhanced phenolic profile and superior overall acceptability of the end product[84].

In conclusion, ginger's diversified applications in dairy products have demonstrated its vast potential as a functional ingredient. Among the different forms of ginger, ginger extract came up as an extensively employed form, followed by ginger juice, powder, and essential oil. Ginger extract exhibited its aptitude for improving the overall techno-functional characteristics of dairy products and offering persuasive coagulation properties for cheese manufacturing. While the use of all forms of ginger proved to be effective in elevating the functionality and efficacy of dairy products, at the same time, some quality and hedonic characteristics were also compromised, but the incorporation of ginger extract was identified with higher functional and physicochemical improvements and minimal quality defects.

8.3 Beverages

Like other food sectors, the incorporation of functional food ingredients including ginger has also been investigated in beverages. In the manufacturing of a ready-to-drink ginger–cocoa beverage, ginger powder, and cocoa were optimized at an 8% concentration with low-fat cocoa powder, respectively, as higher concentrations of ginger and fat interfere with two decisive quality factors, sedimentation and viscosity[85]. A successful attempt was

also made to develop a ready-to-drink and ready-to-reconstitute ginger-based beverage with superior functionality and a 6-month shelf life at ambient temperature[86].

Ginger extract in combination with lemon juice rendered an excellent job as a natural preservative in a carrot–mandarin ready to serve (RTS) drink. During storage, a few modifications were observed in the physicochemical properties, but the product characteristics remained consistent to a large extent[87]. A ginger and Indian gooseberry-based herbal beverage was also prepared and investigated by replacing sugar with aspartame, an artificial sweetener[88].

Liu *et al.*[89] recommended atmospheric pressure sterilization for a ginger-flavored beverage due to its feasibility and capability to retain the important volatile compounds. Fresh ginger extract was adequately exploited in the production of a ginger-based functional carbonated beverage. The functionality and sensorial characteristics of the drink were improved with the addition of ginger rhizome extract, but the shelf life was largely associated with the carbonation level of the product[90]. In another study, supercritical extraction was mentioned as a superior extraction approach among conventional and ultrasonic extraction techniques, while mint was detected with marginally better phenolic and antioxidant profiles than ginger. A ginger–mint drink of high nutraceutical value was prepared at 0.4% concentrations of each extract with favorable physicochemical and hedonic characteristics[91].

Ginger has also been formulated in various functional beverages in the form of blends with different spices, herbs, fruits, and other food ingredients. Soybean, ginger, and mango-based functional drinks were developed to effectively exploit the nutritional and functional values of these ingredients, which were consequently attributed with feasible sensorial properties and overall acceptability[92]. An optimum formulation (*v*/*v*) was furnished for a functional beverage utilizing ginger extract (15.1%), tamarind extract (9.9%), turmeric extract (5.0%), sugar solution (40%), and water (30%). A ginger-based beverage with hyperthermic activity was also found to be efficient against peripheral skin extremities in women experiencing mild cold sensitivity[93].

The integration of two different food ingredients could ameliorate the defective quality attributes of the intended food product. The fusion of a better coloring feature from tea and a favorable flavoring attribute from ginger resulted in a superior acceptable beverage product[94]. During an antioxidant evaluation in tea-ginger extract, the powder concentration was reported as the most influential process parameter than the time and temperature[95]. The supercritical ginger extract (0.3%) was preferred over the conventional ginger extract in iced ginger tea and functional coffee substitute production due to its exceptional performance, safety, purity, and overall acceptability[96,97]. Ginger extract (10%) was formulated and optimized with non-decaffeinated robusta coffee (40%) with an improved functional value and without any adverse effects on the sensorial and quality characteristics[98,99].

8.4 Meat and fish products

Several investigations and experiments were also conducted to figure out the effects of ginger and its derivatives in various forms on meat and fish products. Rabbit meat burger patties were fortified with ginger powder at two different concentrations (1% and 2%) and significantly improvised the fatty acid profile by accelerating the polyunsaturated fatty acids[100]. Ginger powder also increased the antioxidant capacity and reduced lipid peroxidation, subsequently providing a meat product with better shelf life and enriched nutritional status. Mancini *et al.*[101] also designed an experiment to enhance the quality of pork burgers through ginger powder incorporation. The physiochemical attributes, antioxidant capacity, fatty acid profile, microbial growth, and lipid oxidation of the ginger powder-enriched pork burger were evaluated, and the results were in agreement with the previous study. In another investigation, ginger was designated as a potential alternative of artificial antioxidants in pasteurized canned meat products[102]. Ginger and papain powders were also competently exploited as natural tenderizing agents in buffalo calf meat[103].

A comparative analysis was conducted to assess the effects of three different spices as potential organic preservatives in raw chicken meat products. Clove powder (0.2%), even in a very small quantity, compared to ginger (3%) and garlic (2%) pastes, performed very well to improve the oxidative stability, physicochemical properties, and antimicrobial activities in raw chicken meat with refrigerated storage[104]. Ginger and pineapple juices had also been examined as promising marinating agents in raw and cooked goat meat[105].

Ginger juice not only provided oxidative stability but also developed the hedonic features by imparting a bright red color and strong marinating odor and reducing the gamey flavor of Saanen goat meat. In another investigation, papain juice was described as a better tenderizing agent than ginger and pineapple juices, as it induced a mild disruption in the muscles of goose meat[106]. Fermented ginger paste was characterized along 25 metabolites with substantial antimicrobial activity, and its application on chicken meat efficiently enhanced the shelf life through a significant reduction in the microbial load[107]. Similar findings were also reported by Abdel-Naeem and Mohamed[108] regarding the application of ginger and papain extracts in camel meat patties. Sukada *et al.*[109] stipulated that pineapple extract had superior hedonic characteristics than papaya leaf and ginger extracts when practiced on Bali beef through the immersion method.

Research has shown that ginger is as effective as sodium ascorbate in combating oxidative rancidity, and it also enhances the textural and sensory properties of meat products more effectively than synthetic antioxidants[110]. Additionally, ginger extract proved to be effective for smoked buffalo meat, as its microbial, physicochemical, and sensory characteristics remained stable without significant changes throughout the storage period.

Ginger extract not only helped regulate and maintain microbial levels within acceptable limits but also improved the functionality of cooked meat products[111]. For instance, smoked mackerel fish treated with 5% ginger extract demonstrated enhanced shelf life and hedonic qualities. The ginger extract significantly boosted the stability and functional value of the smoked fish due to its antimicrobial and antioxidant properties. Additionally, the sensory quality of the fish treated with ginger extract remained superior and more consistent compared to other treatments, even during storage. Mattje *et al.*[112] revealed that the antioxidant activity of the supercritical ginger extract is stronger than that of ginger essential oil, as shown in the treatment of tilapia fish burgers. The supercritical ginger extract extended the shelf life of fish burgers from 6 to 8 days, though it negatively impacted the overall taste perception due to its intense spicy flavor.

A variety of synthetic tenderizers and proteolytic enzymes have been engaged in the tenderization of meat. Currently, natural tenderizers are in demand due to certain constraints of synthetic

tenderizers such as safety issues, unpleasant tastes, and over-tenderization. Ginger extract (5%) was recommended as a potential tenderizer for Yak meat as it enhanced the cooking yield, tenderness, and lipid oxidative stability during storage[113, 114].

9 Future prospects

Ginger-based nutraceuticals can serve as supplements to support disease management and promote a healthy lifestyle. The development of additional ginger-based products is encouraged to create a wider range of functional foods, appealing to a broader audience. In the pharmaceutical industry, ginger supplements can be formulated as individual compounds or phytocomplexes. After pre-clinical and clinical research, these supplements could be used as complementary treatments for immune-related diseases. Future collaboration among researchers from fields such as chemistry, biology, clinical science, pharmacy, and the food industry is essential to explore ginger's effects on human immunity further. Partnerships between researchers and industry will help accelerate advancements in ginger applications. Additional studies are needed to focus on the efficacy, optimization, and incorporation of ginger bioactives into food products without compromising their physical and sensory qualities. Investigating the potential synergistic effects of ginger bioactives with other compounds and conducting toxicity studies of these compounds in their purest form is also crucial to ensure their safe use.

To optimize ginger's medicinal, agronomic, and economic potential, future studies should concentrate on filling in the gaps and contradictions in the existing body of information. To confirm the effectiveness of ginger through extensive, multi-center clinical trials for ailments like cancer, metabolic disorders, and chronic inflammation, further research is required to clarify the molecular mechanisms of its bioactive constituents, such as gingerols and shogaols. Thus, it has been proved by numerous investigations that these can be used for phytomedicine in the future. However, further research is needed to regulate the development of disease by modifying metabolic, genetic, and antioxidant activities. Therefore, to address the functional properties of ginger, a more thorough study using specific approaches and a large number of clinical studies is needed. Present-day therapies for a variety of human illnesses rely on the use of synthetic medications that provide positive outcomes. These do, however, also exhibit negative side effects. Gingerol has many components that are highly effective against a wide range of human illnesses, including cancer, diabetes, obesity, and cardiovascular disease. Additionally, these ingredients are reasonably priced and safe. As a result, gingerol and its components have raised hopes for new and innovative treatment approaches to various illnesses. The molecular pathway underlying gingerol's mechanism of action requires further investigation to pave the road for its widespread application. Standardizing dosage guidelines and administration techniques is still essential, as is conducting long-term safety assessments, especially for more susceptible populations. Along with research into its incorporation into functional meals, beverages, and nutraceuticals, sustainable farming methods and genetic engineering should be investigated to improve ginger cultivation in the face of climate change. Additionally, research on the synergistic effects with other compounds and possible contraindications might maximize therapeutic uses, and cooperation with ethnobotanists can bridge traditional and modern knowledge. Furthermore, in order to direct innovation and production scalability, a thorough examination of the worldwide market dynamics of ginger and its economic impact is necessary. By addressing these issues, we can better comprehend the various uses and advantages of ginger.

10 Conclusion

Ginger has been shown to contain many chemical constituents, including volatile oil, gingerol analogues, diarylheptanoids, phenylalkanoids, sulfonates, steroids, and monoterpenoid glycosides, as demonstrated by multiple investigations. Ginger exhibits therapeutic properties that hold the potential to protect gastrointestinal processes, improve liver and kidney function, and prevent diabetes. It is particularly effective in preventing cancer and alleviating vomiting and nausea. These benefits can be ascribed to the presence of gingerols, paradols, and shogaols. However, in addition to its ability to enhance the taste and flavor of food, ginger may also be used as a highly effective herbal medication due to its numerous therapeutic effects that have been observed in translational studies. Nevertheless, additional clinical studies are required to thoroughly assess the effectiveness and safety of ginger. The results of this analysis are advantageous for evaluating the clinical use of ginger in treating complex disorders and could perhaps lead to new treatment possibilities.

Data availability

Not applicable.

Conflicts of interest

The authors declare that there are no conflicts of interest in this work.

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None.

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