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REVIEW PAPER

EXPLORING THE POTENTIAL OF GINGER (*Zingiber officinale*) IN FOOD INDUSTRY

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Abstract

Ginger (*Zingiber officinale*) is a widely utilized spice with a rich history in culinary and medicinal applications across diverse cultures. In this review, ginger is considered not only as a spice but also as a food ingredient, since in food science the term *ingredient* refers to any component—used in large or small amounts—that contributes flavor, aroma, preservation, or health-promoting functions in food formulations. Ginger exhibits excellent potential to be developed as a food ingredient, due to its rich nutritional composition and bioactive compounds, contributing to increasing public interest in various ginger products. To enhance ginger's potential as food ingredients, modern processing technologies, such as drying, fermentation, and nanotechnology have been developed to improve product quality and functionality. Furthermore, its rich bioactive profile suggests that ginger can be effectively utilized to create functional food products with health benefits. Future studies should focus on innovative processing and formulation strategies to to produce highly acceptable and functional ginger products.

Keywords: Ginger rhizome, food ingredient, functional food, bioactivity, spices

Introduction

Ginger (*Zingiber officinale*) is a major spice plant influencing human life. This plant is distributed in Asia, Africa, and America. Since long ago, people have known about ginger as a culinary spice and a conventional therapeutic for various illnesses

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(Shaukat *et al.,* 2023). The use of ginger in this context shows this plant's historical significance and relevance to people's lives.

In addition to its medicinal and culinary use, ginger holds significant importance in the gastronomic traditions of numerous nations. In India, ginger is utilized in everyday cuisine and herbal beverages such as ginger tea. In Japan, ginger is presented as an accompaniment to sushi in the form of gari (pickled ginger). In Western nations, ginger is frequently used in baking, beverages such as ginger ale, and various food products. In Indonesia, ginger is a spice in numerous meals and herbal beverages. Beyond these traditional uses, ginger has also gained popularity in value-added products such as syrups, candies, and ready-to-drink beverages. Although widely recognized as a spice, in the food industry ginger is also regarded as a food ingredient, since it is incorporated into a variety of formulations including bakery products, beverages, and confectionery.

Numerous studies have demonstrated that ginger exhibits several bioactivities that are advantageous for health. Reported qualities encompass anti-inflammatory, antioxidant, and antibacterial activities, which aid in ameliorating illnesses such as diabetes, heart disease, and digestive issue (Lai *et al.,* 2016; Unuofin *et al.,* 2021). The primary bioactive constituents of ginger, including gingerol and shogaol, significantly contribute to the enhancement of lipid metabolism and the mitigation of inflammation (Liu *et al.,* 2020). Moreover, the bioactive constituents in ginger help reduce blood glucose and cholesterol levels, consequently enhancing the condition of individuals with type 2 diabetes. Gingerol has been demonstrated to function as a chemo preventive drug, capable of inhibiting cancer cell proliferation (Unuofin *et al.,* 2021). The diverse bioactivities of ginger have increased demand, reflecting the consumers' rising recognition of the significance of nutritious food. The advancement of technology has created the potential to enhance the quality and efficacy of ginger in multiple uses, especially within the food industry. Contemporary technologies like nanotechnology and eco-friendly solvent extraction provide more effective and efficient ginger processing, improving its medicinal constituents' stability (Uddin *et al.,* 2023). In the worldwide food sector, there is a rising demand for ginger-derived goods. The growing popularity of a healthy lifestyle is propelling the use of products like ginger herbal tea, ginger-infused fizzy beverages, and nutritious snacks with ginger. These items provide distinctive flavor and health advantages (Duque-Soto *et al.,* 2023).

Technological innovation is essential for improving the competitiveness of ginger-based products. Contemporary technology has demonstrated the ability to improve the efficacy of ginger. Nano-emulsion technology can diminish the particle size of ginger in formulations, hence improving absorption by the body. Eco-friendly extraction techniques, such as supercritical CO_2, can extract beneficial chemicals from ginger, while preserving its quality. This technique enhances production efficiency, while ensuring sustainability in ginger processing (Uddin *et al.,* 2023).

This review aims to examine the potential of ginger as a food ingredient by thoroughly analyzing recent research on its health benefits. This essay also examines the developed ginger processing technologies and their impacts. This review offers an expansive viewpoint on advancements in ginger processing technologies that may facilitate the future development of ginger-based products.

Diversity of ginger rhizome products

Processing of the ginger rhizome yields a variety of products, including fresh ginger, dried ginger, preserved ginger, ginger powder, ginger oil, ginger oleoresin, and ginger paste. Each of these products has distinct physicochemical properties and associated advantages, contributing to their diverse application in the food and health sectors.

Fresh ginger

Fresh ginger refers to rhizome that has not undergone any processing. Fresh ginger is used in culinary applications as flakes, grated, or paste. Compared to other agricultural commodities, fresh ginger exhibits relative resilience to damage owing to its low moisture content and protective features (Mishra and Kumar Bhatt 2016). In addition to imparting a unique flavor and fragrance, fresh ginger comprises essential bioactive constituents, including gingerol and shogaol. These chemicals possess health benefits, including antioxidant and anti-inflammatory characteristics (Shahrajabian *et al*., 2019).

Dried ginger

Dried ginger is derived from fresh ginger that undergoes specific drying processes. Conventional sun and oven drying are the most frequently employed drying techniques (Mustafa *et al*., 2019). Dried ginger is abundant in phenolic compounds and possesses potent antioxidants. This results from transforming gingerol molecules into shogaol (Li *et al.,* 2019). Studies indicate that dried ginger might improve oxidative stability in food items, including mayonnaise, suggesting its potential as a natural preservative (Kasi *et al.,* 2017).

Preserved ginger

Ginger preserves are derived from fresh ginger combined with sugar or salt to prolong their shelf life. Besides its primary role in prolonging shelf life, the additional sugar or ginger imparts a distinctive sweet or Savory flavor. This product is applicable in numerous culinary preparations, encompassing desserts and snacks. Studies indicate that ginger preservation can diminish microbial proliferation, improving food safety. The water content and vitamin C levels in preserved ginger are inferior to those in fresh ginger.

Ginger powder

Powdered ginger is produced by pounding dried ginger into a fine powder. The typical size attains 50 to 60 mesh. This product is highly sought after in the food and beverage sector and is an addition to health products. Ground ginger is antibacterial and is a natural preservative in many food products, such as juices and processed foods (Murthy *et al.,* 2015).

Ginger oil

Ginger oil is derived from ginger rhizomes by multiple extraction techniques. Ginger oil is globally acknowledged and utilized in the pharmaceutical and food sectors. Ginger essential oil generally comprises 95%–99% volatile compounds, with an oil yield of 1%–4% from dry ginger, and α-zingiberene is a notable constituent. The chemical makeup of ginger essential oil is affected by geographical origin, cultivar, harvest period, drying procedures, and extraction techniques (Uddin *et al.*, 2023). Ginger oil possesses potent antibacterial capabilities, rendering it appropriate as a natural preservative in food goods (Aldhalemi *et al.*, 2023).

Ginger oleoresin

Ginger oleoresin contains essential oils and non-volatile constituents derived from ginger. The food sector progressively prefers ginger oleoresin as a secure disinfection agent. This substance may serve as a natural preservative because it can impede microbial growth. Oleoresin exhibits a wide range of antibacterial efficacy against pathogenic microorganisms responsible for food degradation (Murthy *et al.*, 2015). Ginger oleoresin serves multiple purposes, particularly in the food and pharmaceutical sectors, as a safer substitute for synthetic preservatives.

Ginger paste

Ginger paste is obtained by crushing fresh ginger with a small amount of water (Zhang *et al.*, 2016). This product is frequently utilized in Asian cuisine and possesses a robust flavor. Ginger paste possesses a piquant flavor akin to that of fresh ginger. The brownish hue results from non-enzymatic processes occurring during manufacture and storage. Ginger paste serves as a condiment in numerous meals, imparting a unique spicy flavor (Choi *et al.*, 2012).

Table 1 delineates the specific benefits associated with each product form, providing a comprehensive overview of their distinct characteristics and applications.

Ginger as a main ingredient

Ginger is increasingly used in nutritious, vegan, and functional foods, adding a zesty flavor to salads, soups, and smoothies while enhancing nutritional benefits. It is also incorporated into functional products like supplements for digestive health (Mao *et al*., 2019). Research highlights ginger's valuable macronutrient and micronutrient composition, as analyzed in this document (Table 2).

As presented in Table 2, ginger possesses a comprehensive nutritional profile that enhances its viability as a food ingredient. Fresh and powdered ginger comprise carbs (18–80.67%), serving as an energy source, crude fiber (2–76.4%), which promotes digestive health, and modest levels of protein and fat that enhance a balanced nutritional profile.

Table 1. Compilation of food and beverage products utilizing various ginger forms, with associated benefits.

Type of ginger form used	Product	Health benefit	Reference
Fresh ginger	Ginger tea	Causes synergistic antioxidant effects, reduces nausea.	Makanjuola (2017)
	Ginger juice	Lowers cholesterol, antioxidants	Prasad *et al.* (2012)
	Ginger ale	Improves digestion, antioxidants, increases immunity	Pujiati *et al.* (2022)
Dried ginger	Infused water	Antioxidants, lose weight, source of vitamins, minerals, and fiber.	Sepriani and Deswandi (2021)
Preserved ginger	Gari (pickled ginger)	Improves digestion, increases appetite	Chang *et al.* (2011)
	Candied ginger	Antioxidants, reduces nausea, source of energy	Afzaal *et al.* (2021)
Ginger powder	Ginger cookies	Anti-inflammatory, extends shelf life, unique flavour	Shaukat *et al.* (2023)
	Gingerbread	Antioxidants, antibacterial	Arnold *et al.* (2022)
Ginger oleoresin	Ginger candy	Antioxidants, lowers cholesterol, antimicrobial	
	Carbonated drinks	Facilitates digestion, increases immunity, lowers cholesterol, warms the body	Said *et al*. (2015)
Ginger paste	Ginger paste	Increases shelf life	Afzaal *et al.* (2021)

Table 2. Macronutrient and micronutrient composition of ginger.

Types of ginger	Macronutrient components (per 100 g)	Micronutrient components (per 100 g)	Reference
Fresh ginger	Carbohydrates (18 g), fibre (2 g), fat (750 mg).	Vitamin C (5 mg), vitamin E (260 mcg), vitamin K (0.1 mcg), Thiamine (25 mcg), riboflavin (34 mcg), Niacin (750 mcg), vitamin B6 (160 mcg), Ca (16 mg), Mg (43 mg), K (415 mg).	Pratap *et al.* (2017)
Ginger powder	Crude protein (5.45g), crude fibre (10.36g)	Zn (4.19 µg/g), Ca (34.55 µg/g), Fe (1.59 µg/g)), Mn (18,90 µg/g)), Na (38.96 µg/g), K (36.34 µg/g)	Ogbuewu *et al.* (2014)
Ginger powder	Protein (9.62g), fat (3.24g), crude fiber (8.28g), ash (6.74g), carbohydrates (62.03g)	Na (0.064g), K (1.73g), Mg (0.203g), Ca (0.087g), P (0.161g), Fe (23.05 mg/Kg)	Ajagun *et al.* (2017)
Ginger powder	Crude fibre (76.4g), crude protein (7.88g), fat (5.03g)	Vitamin C (3.75g), Zn (12.23 mg), Fe (80 mg), Mn(7.33 mg), Ca (0.49 mg), Mg (1.2 mg)	Shahid and Hussain(2012)

Ginger is abundant in micronutrients, including vitamins C, E, B-complex, and critical minerals like calcium, potassium, magnesium, iron, and zinc, which enhance immune function, metabolism, and bone health. Bioactive constituents, like carotenoids and manganese, confer antioxidant and anti-inflammatory characteristics, rendering them suitable for functional goods. The amalgamation of these elements renders ginger appropriate for conversion into health beverages, culinary spices, dietary supplements, or high-value processed food items.

The potential use of ginger in the development of functional foods

The concept of a 'functional food' pertains to foods that provide health benefits beyond basic nutrition, often due to the presence of bioactive compounds (Shahrajabian *et al.*, 2019). Ginger, historically recognized as a global spice, also possesses the potential as an ingredient in the development of functional foods.. This is attributable to its comprehensive nutritional profile and bioactive constituents. Ginger contains bioactive substances such as gingerol and shogaol. Numerous researchers investigated gingerol and shogaol in ginger and their associated health benefits (Table 3).

Table 3. Bioactivity of gingerol and shogaol and their mechanisms.

Function	Mechanism	Reference
	6-Gingerol	
Antioxidants	Antioxidant activity, scavenging capacity for DPPH• and ABTS	Ali *et al*. (2018)
	Regulates lipogenesis, fatty acid oxidation, oxidative stress, and mitochondrial dysfunction	Li *et al*. (2019)
Anti-obesity	Promotes fat browning and regulates lipid metabolism	Saravanan *et al.* (2014)
Anti diabetes	Reduces blood glucose, total cholesterol in diabetic patients	Garza-Cadena *et al.* (2023)
Anti-inflammatory	Downregulates key proteins of NF-κB/MAPK signalling pathway	Grzanna *et al*. (2005)
	Decreases levels of inflammatory factors and inducible NO synthase	Liu *et al*.(2020)
Antimicrobial	Reduces microbial load in camel meat and edible offal	Tang *et al*. (2020)
	6-Shogaol	
Antioxidants	Increases intracellular GSH/GSSG ratio; reduce ROS levels	Chen *et al*.(2014)
Anti-inflammatory	Inhibits PI3K/Akt and NF-κB signalling pathways in intestinal epithelial cells.	Luettig *et al*.(2016)
	Inhibits NO and PGE 2 production	Zhang *et al*. (2016)
Cytotoxic	Inhibits STAT3 and NF-κB signaling;	Saha *et al*. (2014)

Ginger is classified as a functional food because of its bioactive components. As summarized in Table 3, various studies have demonstrated that ginger possesses antioxidant, anti-obesity, anti-diabetic, anti-inflammatory, antimicrobial, and other biological activities. The two primary compounds that contribute significantly to ginger's bioactivity are gingerol and shogaol (Jiang, 2025). While these compounds have different physical properties, they also exhibit distinct mechanisms of biological activity (Zhang, 2024).

Table 3 illustrates the differences in antioxidant activity mechanisms between 6-gingerol and 6-shogaol. Research indicates that the antioxidant effectiveness of gingerol and shogaol is greatly influenced by factors such as the structure of their side chains, the reaction medium, and the substrate involved (Lu, 2014). Shogaol is reported to have a higher antioxidant potential than gingerol, attributed to the presence of α, β-unsaturated carbonyl functional groups (Ali *et al*., 2018). These functional groups arise from alterations in the β-hydroxyl ketone group in gingerol, resulting from dehydration facilitated by an acid catalyst and thermal conditions. In summary, both gingerol and shogaol exhibit transformational properties (Kou *et al*., 2018).

The benefits of ginger as a food ingredient

Ginger has a unique flavor that is widely appreciated. Moreover, its nutritional composition and bioactive components confer a considerable advantage to ginger as a culinary ingredient. Ginger has been extensively farmed globally, enhancing its accessibility as a culinary ingredient.

Utility and health advantages

Ginger is a multifaceted spice containing significant bioactive components, including gingerol, shogaol, and zingerone. Gingerol, the principal ingredient in ginger, possesses potent anti-inflammatory and antioxidant capabilities, safeguarding the body from free radical damage and the potential onset of degenerative diseases and exhibiting a free radical scavenging capability of up to 90% at specific concentrations (Kausar *et al.*, 2017). Ginger is a source of vitamins and minerals, including vitamin C (5 mg/ 100 g), magnesium (43 mg/ 100 g), and potassium (415 mg/ 100 g) (Mao *et al.*, 2019), which facilitate immunological, muscular, and neural processes. The flavonoid content in ginger offers antioxidant, anti-ageing, and anti-cancer advantages, exhibiting antioxidant activity with an IC_{50} of 15 µg/mL (Zhang *et al.*, 2016). Ginger has demonstrated efficacy in diabetes management, with studies indicating a reduction in HbA1c by as much as 0.5% and insulin levels by up to 3.5 µU/mL in patients with type 2 diabetes after 12 weeks (Garza-Cadena *et al.*, 2023). Ginger, rich in bioactive components, is a flavor-enhancing spice and a functional food element promoting health.

Fragrance and distinctive taste

Ginger is recognized for its distinctive flavor, spiciness, warmth, and scent, rendering it a highly esteemed component in diverse global cuisines. The peculiar flavor originates from the volatile chemicals in ginger, which contribute distinctive qualities to numerous dishes, particularly in Asian cuisine. Discovered 49 volatile molecules in ginger essential oil, predominantly monoterpenes. The ginger rhizome possesses a distinctive spicy flavor, attributed to the presence of gingerol chemicals, predominantly [6]-gingerol, [8]-gingerol, and [10]-gingerol (Johnson *et al.,* 2021). Aromas akin to orange or rose have been detected in fresh ginger. Six chemicals responsible for that scent were identified: citronellal, citronellol, geranial, geraniol, linalool, neral, and octanal (Schaller and Schieberle, 2020). Volatile molecules contribute many scents, including monoterpenes, sesquiterpenes, and their oxygenated derivatives. Specifically, geranial, eucalyptol, β-linalool, bornyl acetate, α-terpineol, heptan-2-ol, endo-borneol, zingiberene, γ-terpinene, terpinolene, and α-pinene, which display mint, citrus, and sweet characteristics. Floral, cold, woody, and pine-like scents were recognized as the predominant fragrance components (Yu *et al.,* 2022). The distinct flavor of ginger renders it a flexible component in numerous culinary applications, spanning from main courses to desserts. Ginger can be included in cakes, biscuits, and nutritious beverages, imparting a unique flavor and augmenting the sensory experience (Justo *et al.,* 2015).

Suitable for human consumption as food

The distinctive properties of ginger and its bioactive component composition are the primary factors driving widespread attention. Conversely, food safety considerations must also be addressed. While ginger has historically been recognized and utilized as a traditional remedy, its role as a culinary ingredient necessitates an assessment of safety when ingested as food. Ginger has generally been deemed "safe" by the Food and Drug Administration (Beristain-Bauza *et al.,* 2019). The primary critical control points for ensuring the safety and quality of ginger include chemical constituents (active compounds such as gingerol and potential toxins like methyl eugenol), contaminants (microbiological agents, pesticides, heavy metals, and residual solvents), and the risk of adulteration (Stanisiere *et al.,* 2018). Numerous studies investigate the adverse effects of ginger consumption. Ginger has no risk of side effects or bad outcomes during pregnancy. Not significant difference between the cohort of pregnant women exposed to ginger during the first trimester and those exposed to non-teratogenic medications (Portnoi *et al.,* 2003). Among 68,522 women in Norway, reported a number of 1020 women (1.5%) who consistently ingested ginger did not exhibit an increase in congenital abnormalities, stillbirths, low birth weight, or preterm deliveries (Heitmann *et al.,* 2013). Additional research is required to assess the side effects of ginger use on food safety.

Accessibility and durability

Recently, the prevalence of food insecurity has escalated. This is intimately connected to food accessibility. Ginger is an agricultural commodity that is facile to develop and has strong resilience. This plant may thrive in diverse soil types, excluding rocky and wet terrain. Ginger plants may thrive in various places, including Indonesia, India, and China. The plentiful supply of ginger renders it an accessible food source for the people (An *et al*., 2016). Ginger offers numerous advantages as a culinary ingredient, including substantial nutritional content, various health benefits, distinctive flavors, and favorable availability and longevity. Due to its numerous advantages, ginger merits recognition as a significant component of a nutritious diet.

Recent investigations on ginger as a food ingredient

Ginger has garnered significant study attention owing to its health advantages and prospective uses in food products. Recent research indicates that ginger functions as a culinary spice and a functional food component that provides numerous benefits. To illustrate the diverse applications of ginger in food product development, Table 4 presents a compilation of relevant studies.

Table 4. Investigations about the advancement of food products derived from ginger.

Products	Result	Reference
Gingerbread	Diverse sweeteners like sorbitol, xylitol, cane sugar, and maple syrup can successfully substitute refined beet sucrose in gingerbread while maintaining physical and sensory quality.	Ivanišová *et al.*(2023)
Gingerbread	Incorporating plant-based ingredients in gingerbread products markedly enhances their nutritional and biological value, resulting in a protein content increase of 21.9% to 22.9% and a fat content rise of 5.7% to 24.5%.	Kravchenko and Yaroshenko (2017)
Ginger Cookies	Cakes prepared with ginger and whole wheat banana flour exhibit an improved nutritional profile, featuring elevated protein, fat, and crude fibre levels compared to whole wheat cakes.	Adebayo-Oyetoro *et al.* (2016)
Ginger Coffee	Coffee alternatives derived from ginger with subcritical water exhibit excellent functional features and sensory characteristics akin to traditional coffee.	Švarc-Gajić *et al.* (2017)
Ginger candy	The optimal preservation of ginger and candy is determined by general acceptability, with sugar concentration exerting the most substantial influence. The sugar content also affects colour, flavour, and texture.	Siddiqui *et al.* (2012)
Ginger tea	The extraction temperature, duration, and powder concentration markedly affect the antioxidant levels in ginger tea (2:1). The powder concentration exerts the most significant influence.	Makanjuola (2017)
Ginger beer	The formula for ginger ale with a 75% substitution of palm sugar is the most favoured among the panellists.	Dwiloka *et al.* (2020)
Ginger paste	Incorporating egg powder and ginger flour into the pasta markedly enhances its protein content and antioxidant characteristics, especially the DPPH radical scavenging activity.	Oke *et al.* (2024)
Ginger biscuit	Adding ginger powder to biscuits markedly elevates the protein, ash, and fibre content while diminishing the nitrogen-free extract (NFE) level, improving the biscuits' nutritional value.	Kausar *et al.* (2017)

The role of modern technology in ginger processing for food ingredients

Ginger is a spice of significant commercial significance, extensively utilized in the culinary industry and traditional medicine. Modern technological advancements have substantially enhanced ginger processing, encompassing extraction, drying, fermentation, and nanotechnology applications. Contemporary technology is essential in the processing of ginger as a premium culinary ingredient, emphasizing the diverse methods employed and their effects on ginger's quality and functionality.

Extraction technologies

Extraction technology is vital for converting ginger into oleoresin to maximize its bioactive components. Traditional methods like organic solvent extraction and hydrodistillation remain widely used due to cost-effectiveness but have limitations in energy efficiency, extract quality, and environmental impact (Kamaruddin *et al.*, 2023). Thus, modern extraction techniques continue to be explored. Ultrasonic extraction efficiently disrupts plant cell walls, achieving high recovery rates for gingerol and shogaol (Mao *et al.*, 2019). Supercritical CO_2 extraction preserves bioactive compounds while minimizing thermal degradation and reducing costs (Khan *et al.*, 2021). Additionally, enzymatic techniques enhance bioactive compound release and maintain component integrity (Yu *et al.*, 2022). Combining various extraction methods may optimize ginger extract quality and functionality.

Drying technologies

Drying processes are prevalent preservation methods employed to prolong the shelf life of ginger. Commonly employed drying techniques encompass sun, air, convective, and freeze-drying. The drying technique significantly influences the quality of desiccated ginger. For instance, freeze drying enhances total phenolic content, but alternative drying methods considerably diminish it (An *et al.*, 2016). A separate study indicated that freeze drying is superior, followed by convective drying methods, relative humidity, infrared, and microwave procedures (Osae *et al.*, 2019).

A further study indicated that solar drying procedures yielded the most significant enhancement, although freeze drying achieved the highest total phenolic value compared to solar and oven methods (Mustafa *et al.*, 2019). Conversely, the microwave method yields the fewest bioactive molecules relative to alternative approaches.

The swift and high heat generated by microwaves damages bioactive substances, potentially altering their chemical structure and degrading polyphenol content during drying (Osae *et al.*, 2019). The concentration of 6-gingerol in ginger rose following microwave drying methods. The freeze-drying method preserves the 6-gingerol concentration in dried ginger, maintaining levels comparable to fresh ginger, whereas the air-drying process considerably reduces this compound. The antioxidants in ginger show an enhancement following drying using freeze-drying, sun-drying, and air-drying methods (Kurniasari *et al.*, 2022). Conversely, spray drying, while effective for large-scale production, may result in the loss of certain volatile chemicals due to thermal exposure. Vacuum drying, which reduces heat degradation, is very efficient in maintaining the flavor profile of ginger (Gull *et al.*, 2012). The suitable drying technique not only prolongs the shelf life of ginger but also augments its applicability in several culinary uses.

Fermentation and biotechnological applications

Fermentation is a time-honored and extensively employed method for digesting fresh vegetables, preserving them, and prolonging their shelf life (Swain *et al.*, 2014). The ginger utilized as the raw material is often young and fresh, subsequently acidified with a certain quantity of salt. Subsequently, it undergoes fermentation in anaerobic circumstances. Several groups of compounds such as alkenes, alcohols, aldehydes, and esters constitute the primary volatile constituents in fermented ginger (Chang *et al.*, 2011) however, after fermentation, the concentration of volatile compounds, including zingiberene, α-curcumin, β-sesquifelandrene, geranyl acetate, and citronellyl acetate, is more significant in inoculated fermentation compared to natural fermentation. These chemicals may offer superior health advantages compared to non-fermented ginger (Žitek *et al.*, 2020). This research additionally discovered that the bacteria present in ginger pickles, such as Psychrobacter and Lactobacillus, are linked to volatile chemical compounds. These bacteria possess the capacity to function as probiotic agents that may enhance digestive health. Additional research indicates that fermented ginger extract may be an effective anti-inflammatory agent (Justo *et al.*, 2015). Using fermentation technology on ginger can improve the quality of ginger products as food ingredients and meet the community's demand for functional foods that promote health.

Nanotechnology applications

Nanotechnology significantly influences the food industry. This structural scale has distinct and distinctive functional features (Ali *et al.*, 2024). Nanotechnology has substantially advanced the processing of ginger as a food ingredient, particularly in improving the quality, stability, and efficacy of its bioactive constituents (Zhao *et al.*, 2009). Ginger powder enhanced using nanotechnology optimizes its physical properties, facilitating handling. Ginger powder processed with a planetary ball mill yields nano-sized ginger powder. This grinding can modify the surface morphology, hence influencing its functional qualities. The antioxidant activity in nano ginger powder was superior to that of regular ginger powder (Archana *et al.*, 2020). Superfine ginger powder has an increased surface area, elevated bulk density, reduced repose and internal friction angle, and a high water solubility index. These attributes are beneficial for the industrial management of ginger powder (Zhao *et al.*, 2009).

The nanoencapsulation of ginger essential oil has significant antioxidant activity (IC_{50} = 53.89 μg/mL). Experiments on rats demonstrated that ginger nanoencapsulation effectively reduced inflammation (Maleki *et al*., 2023). Nanoencapsulated ginger extract as a source of antioxidants, anti-cancer compounds, thermal stability and suppression of cancer cell proliferation. This indicates that nanotechnology can be utilized to create functional food products that are both palatable and health-promoting (Mohamed *et al.,* 2023). Consequently, applying nanotechnology in ginger processing can improve its physical and functional attributes. Furthermore, nanotechnology provides efficacy in management and conservation, rendering it more attractive to the public.

The impact of processing on the nutritional composition of ginger

Processing is an essential step in transforming a material into food products. Food processing aims to prolong shelf life, enhance distribution, eliminate hazardous microorganisms, and deliver product attributes that satisfy requirements (Garza-Cadena *et al*. 2023). Diverse processing techniques, including heating, drying, grinding, fermentation, and others, substantially influence the quality of ginger. The processing influences the nutritional makeup of ginger. Nonetheless, it also influences the concentration of bioactive chemicals in ginger associated with its bioactivity.

One important processing method that influences the quality and bioactive content of ginger is drying. Different techniques, including oven, solar, freeze, and spray drying, have varying effects on nutrient retention. Oven drying maximizes flavonoid levels (4.67±0.07%), while mechanical drying produces the maximum alkaloid concentration (4.44±0.04%). Compared to other methods, sun drying maintains superior nutritional and sensory properties. However, gingerol's antioxidant activity can be diminished by excessive heat exposure during drying (Chen *et al*., 2016). A thorough assessment of the effects of various drying techniques on the overall quality of ginger products is given in Table 5. Ginger powder's physical and functional characteristics are greatly influenced by milling. The accessibility of bioactive compounds is improved by finer particle sizes, which raises antioxidant activity (Norhidayah *et al*., 2013). This is essential for increasing ginger's effectiveness in a variety of applications.

Although heating is frequently used to lower the microbial burden, it also affects ginger's chemical composition. Its bioactive composition and sensory qualities are changed by high-temperature processing, which reduces gingerol while boosting its content (Chen *et al.,* 2016). Heating prolongs shelf life by getting rid of germs and fungus, but too much exposure can break the volatile ingredients that give food its flavor and scent. Ginger's health benefits are further maximized by brewing it for 10 minutes at 100°C, which increases its phenolic content and antioxidant activity. However, some active compounds may break down after extended steeping (Norhidayah *et al.,* 2013). Table 5 summarizes the cumulative effects of drying, milling, and heating on ginger's quality, providing insights into optimal processing techniques to retain its functional properties.

Table 5. The impact of ginger processing on the quality of ginger products.

Treatment	Results	Reference
	Drying	
Drying method	The sun drying method maintained the maximum essential oil content (13.9 mg/g) and oleoresin (45.2 mg/g).	Jayashree *et al.* (2014)
Drying temperature	The drying temperature of 60° C, minimized the loss of essential oil to 12.2% and oleoresin to 5.3%.	Jayashree *et al.* (2014)
Oven, microwave, freezing and air drying methods	The freeze-drying method produced the highest total phenolic content (931.94 mg GAE/100 g) and antioxidant activity (82.00%).	Ghafoor *et al.* (2020)
Comparison of fresh and dried ginger with various drying methods (oven, sunlight and freeze drying)	Processed ginger showed higher total phenolic and flavonoid contents compared to unprocessed ginger. Freeze-dried ginger showed the highest levels of phenolic and flavonoid compounds and the highest antioxidant activity.	Offei-Oknye *et al.*(2015)
Drying methods: solar box (SB), solar oven plus solar box (SOSB), conventional (CO), and microwave oven (MO).	Different drying methods significantly affected the nutritional composition of ginger, with microwave oven drying retaining the highest nutrient content and being the most preferred by panelists. All drying methods retained the antimicrobial properties of ginger, making it effective against certain bacterial strains.	Ajayi *et al*. (2017)
	Milling	
Differences in particle size and brewing time	Ginger powder with a particle size of 20 mesh and 5 minutes brewing is optimal in antioxidant activity and sensory evaluation.	Ratnawati *et al.* (2021)
Differences in the particle size of ginger powder 300, 149, 74, 37, and 8.34 µm	The ultra-fine grinding of ginger significantly increases its specific surface area, improves fluidity, water holding capacity, water solubility index, and protein solubility. These characteristics make super-fine ginger powder very suitable for instant food production.	Zhao *et al.* (2009)
	Heating	
Steaming method	Steaming ginger at 120 °C for 4 hours significantly increased its anticancer potential compared to fresh and dried ginger, with the antiproliferative effect on human Hela cancer cells being approximately 1.5 to 2 times greater for steamed ginger. It also increased shogaol levels.	Cheng *et al.* (2011)

Concept for the development of ginger-infused food products

Product development

The innovation of ginger products as culinary ingredients can be realized by integrating ginger with locally sourced items with high nutritional value, such as honey, almonds, or various spices. This combination not only improves the flavor but also boosts the nutritional profile of the finished product. Ginger can be utilized in numerous culinary applications, including preparing nutritious beverages incorporating ginger with other natural components to amplify health advantages (Chen *et al.,* 2024). The creation of ginger products targeted at youngsters and the elderly is also significant. Ginger sweets, ginger beverages, and readily soluble ginger powder might serve as appealing alternatives to augment nutritious intake in these demographics, who frequently necessitate a particular focus on digestive health and immune system reinforcement. Ginger products for children can enhance hunger and bolster the immune system. Moreover, ginger products designed for the elderly might alleviate digestive problems and promote general health; ginger may mitigate nausea symptoms and improve mobility in older adults (Khan *et al.,* 2021).

Technological innovation in processing

Ginger items possess numerous pros and disadvantages. The limited shelf life and bioactive constituents necessitate suitable processing techniques. The utilization of contemporary technology in ginger processing, including extraction, drying, nanotechnology, and fermentation, can enhance the shelf life of ginger while preserving its quality. Ultrasonic extraction methods can improve the release of antioxidant components from ginger, augmenting its bioavailability (Said *et al.,* 2015). Moreover, nanotechnology can facilitate the creation of delivery systems for bioactive molecules derived from ginger, including gingerol and shogaol, which are recognized for their numerous health advantages. Integrating advanced drying technologies and extraction can improve the bioactive profile of ginger, yielding superior-quality products (An *et al.,* 2016). Contemporary packaging innovations, including bright and active packaging, can enhance the shelf life of ginger. Active packaging can regulate humidity and oxygen levels within the package, therefore maintaining the freshness of ginger. Utilizing packaging materials infused with nanoparticles can inhibit microbial proliferation and prolong the shelf life of ginger goods (Mao *et al.,* 2019). This method enables ginger to be processed into more lasting products while enhancing its health benefits for consumers.

Worldwide promotion

Ginger has historically been recognized as a spice for numerous meals. The global promotion of ginger as a health-beneficial food ingredient is essential. This aims to augment the attractiveness of ginger in the global market. Promoting ginger as a functional ingridient and highlighting its diverse bioactivities, including anti-inflammatory, antioxidant, and anti-diabetic properties, requires greater dissemination (Mao *et al.,* 2019). Promoting many traditional goods from different countries, such as ginger tea, candied ginger, and gingerbread, is essential, as it enhances the sensory appreciation of ginger. Conversely, these items offer health advantages and are simple to prepare. The marketing strategy for ginger as a "green economy" product might also be utilized in terms of its contribution to promoting environmentally sustainable eating practices (Gull *et al.*, 2012). By refining this method, ginger may be established as a palatable commodity and advantageous for health and the environment.

Conclusions

This review concludes that ginger, both a spice and medicinal plant holds significant potential as a versatile food ingredient. As a culinary component, ginger is substantiated by extensive data regarding its nutritional composition, encompassing carbs, fibre, vitamin C, and various minerals. Moreover, the bioactive constituents in ginger, specifically gingerol and shogaol, exhibit several antioxidant, anti-inflammatory, anti-diabetic, and antibacterial properties. Ginger-derived goods, including fresh ginger, ginger powder, essential oil, and oleoresin, serve as raw ingredients in the food industry. Processing technology is essential for improving the quality and stability of bioactive components in processed ginger products. With its widespread availability and promise in the worldwide market as a functional food, ginger —traditionally regarded as a spice but also functioning as a versatile food ingredient—provides a sustainable and highly nutritious dietary option.

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