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Potential Applications of Ginger Rhizomes as a Green Biomaterial: A Review

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A B S T R A C T

The rhizome of ginger (*Zingiber officinale Roscoe*), usually known as ginger, is one of the most popular species used in food and traditional medicine. Ginger is rich of various hydrophobic and hydrophilic active compounds with diverse properties. Having fresh aroma, pungent taste, and various health benefits, along with being readily available and inexpensive are the advantages of ginger rhizome. In addition to herbal medicine perspective along with utilization as flavoring agent in foods and beverages, ginger rhizome demonstrated potential application in different fields. In this review, the current evidence of main potential applications of ginger, including its usage in preservation of food and food packaging systems, tenderization of meat product, medical properties, acting as an inhibitor of metal corrosion, biodiesel preservation from oxidation, and its role in the synthesis of metal nanoparticles were discussed. Overall, this review provides valuable information about ginger rhizome as a plant-based material, beyond its role in herbal medicine and imparting flavor to our food.

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Contents

Graphical abstract

1. INTRODUCTION

Ginger is the rhizome of *Zingiber officinale Roscoe*, a perennial herb of the *Zingiberaceae* family [1]. The plant of *Zingiber officinale* was named by an English botanist, William Roscoe in 1807. The name of Zingiber is from the Greek word of ‘zingiberis’ meaning deer’s antlers like shape, while the *officinale* refers to the medical properties of ginger [2]. The ginger plant is indigenous to South-East Asia and then introduced to various parts of globe [3]. Nowadays, it is cultivated in commercial scale throughout the world and is a common crop in Africa, Latin America, and Asia [2].

The rhizome or root of ginger is tuberous and perennial, and the stems are round, erect, oblique and annual [3]. Ginger rhizome was used as condiment to flavor beer throughout middle ages [2]. The flavor of ginger rhizome is combination of spicy, sweet, and peppery along with a very pungent characteristic [4]. Ginger rhizome is commonly consumed as a dried powder, fresh paste, candy, or slices preserved in tea for flavoring as a natural additive [3, 4]. Owing to powerful aroma, the rhizome of ginger is one of the most popular

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worldwide used spices [5]. Moreover, ginger has been widely used in traditional medicine due to its valuable hydrophilic and hydrophobic bioactive compounds [6]. Ginger possesses advantages of inexpensive and nontoxic bioactive compound. The main hydrophobic metabolites of ginger were found to be safe for up to doses of 2000 mg, which is below the guidelines of the U.S. National Cancer Institute Common Toxicity Criteria [2]

Ginger bioactive constituent differ depending on the plant source, extraction method, and the storage conditions [7]. In case of separation and extraction processes, Soxhlet and steam distillation approaches are known as traditional extraction methods, which are widely used for the extraction of bioactive compounds from ginger [8]. Needing hazardous solvents, being tedious to operate, and in some cases operating at high temperature are their limitation [8]. In addition to traditional methods, various advanced extraction methodologies such as supercritical fluid extraction [9], subcritical water extraction [10], microwave-assisted extraction [11], and ultrasound assisted extraction [5] have also been employed to solve the problem associated with traditional extraction methods, mostly the thermal degradation of the desired bioactive compounds [8, 9]. For additional information on extraction processes, one can refer to literature [12].

There are several review articles on various aspects of ginger rhizome. Choi et al. [13] reviewed pharmacotherapeutic potential of ginger rhizome in age-related neurological disorders. Srinivasan [14] published review on ginger rhizome having focused on multiple health properties of ginger. Mao et al. [15] reviewed bioactive compounds of ginger and their mechanisms of action in biomedical applications. Shukla and Singh [3] studied anticancer activities of ginger. Ali et al. [16] reviewed pharmacological and toxicological properties of ginger. Nevertheless, a comprehensive review article on the all-potential applications of ginger rhizome is limited in literature to the authors' best of knowledge.

Considering the advantages of ginger rhizome as a green biomaterial, herein, at first the chemical constituents of ginger rhizome were briefly reviewed. Then, various potential applications of ginger rhizome including its application in food industry for food preservation and meat tenderization, pharmaceutical, metallurgy as metal corrosion inhibitor, fuel industry for biodiesel preservation, and nanotechnology for metal nanoparticle synthesis were comprehensively reviewed.

2. CHEMICAL CONSTITUENTS OF GINGER RHIZOMES

In fresh ginger rhizome, gingerols are the major compounds. The pungency level of fresh ginger is attributed to the concentration of gingerols, which vary depending on the growing conditions, harvesting, and extraction process [18].

Gingerols comprise a series of structural analogs differentiated by the length of their alkyl chains, including [6]-,[8]-and [10]-gingerol [3, 19]. Of these, [6]-gingerol is the most abundant phenolic ketones compound in gingerols (50-70%) with high biological activities [17, 18]. Meanwhile, the hydrophobicity property of [6]-gingerol limits its application [17].

Ginger contains more than 200 different compounds including pungent and active ingredients [17]. Generally, the constituents of ginger can be classified into two groups: volatile oils and non-volatile pungent compounds, which induce aroma and hot sensation in the mouth, respectively. Over 50 compounds of ginger's oil have been characterized, which are mainly sesquiterpenoids (α-zingiberene, α-farnesene, zingiberol, β-bisabolene, and β-sesquiphellandrene) and monoterpenoids (terpineol, borneol, curcumene, and geraniol) zingeberene, [3, 16]. The odor of ginger is mainly associated with these volatile oils [16]. The non-volatile pungent constituents are biologically active phenolic compounds, including gingerols, shogaols, zingerone, and paradols [3]. The chemical structures of the major constituents of ginger are shown in Figure 1.
Zingerones, as pungent constituents of ginger, cannot be found in fresh ginger. It produced from gingerols through reverse aldolization reaction when fresh ginger is heated [13]. After dehydration, gingerols can be transformed to shogaols, which are spicier than gingerols [18, 20]. In fact, the pungency of dried ginger is related to the presence of shogaols [16]. Besides, paradols are also other constituents of ginger formed from hydrogenation of shogaols [3]. In addition to the above mentioned compounds, ginger contains carbohydrates, lipids, waxes, raw fibers, organic acids, vitamins, and minerals. Moreover, proteolytic enzyme named as zingibain was also identified as ginger constituents [15].

3. APPLICATIONS OF GINGER RHIZOMES

In this section, the main applications of ginger rhizomes are discussed. Based on mostly recent publication, they

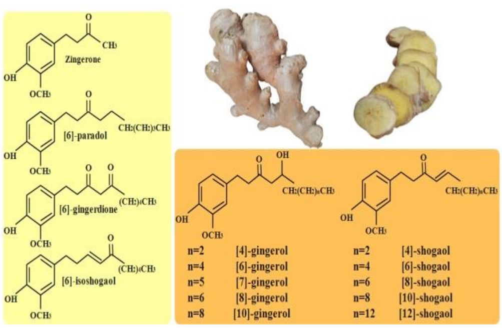

Figure 1. Chemical structure of major components of ginger

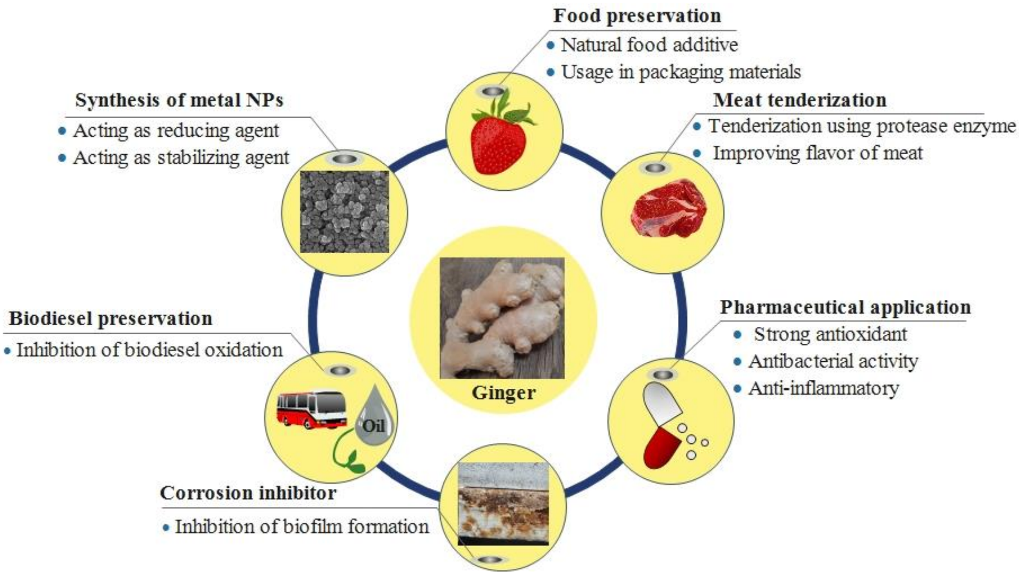

Figure 2. Main overall applications of ginger rhizomes

were classified into six independent categories, as illustrated in Figure 2.

3. 1. Food Preservation The oxidation of lipid and protein along with microbial contamination are the main causes of changes in the food quality [21]. For extending the shelf-life of food products, appropriate intervention is needed. Antioxidant compounds have the capability to terminate the chain reaction mechanism in oxidation process, owing to their ability to capture free radicals and donors electrons [22].

Ginger extract composed of essential oils, volatile odoriferous oil, gingerol, paradol, shogaol, α-zingiberene, α-curcumene, and β-sesquiphellandrene with strong antioxidant and antimicrobial activities. These can act as natural radical scavenger in food and food products instead of synthetic preservatives like butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) [21-23].

Thiobarbituric acid reactive substances (TBARS) assay is a common method for the detection of lipid oxidation in cells and tissues. Addition of ginger extract to Muscovy duck breast muscle [24], sheep muscle [24], and camel meat burger patties [25] reduced TBARS value of samples in compare to control sample (without extract), confirming retardation of lipid oxidation in muscle. This retardation could be attributed to the activities of peroxide-scavenging enzyme and polyphenol compounds in ginger extract [24, 25]. Besides, ginger extract demonstrated positive effect on the quality of canola oil even at temperatures of 60, 90, and 120 °C owing to its strong antioxidant activities [23].

The application of biobased materials that are derived from biological sources instead of petroleum-based polymers is ideally suited to develop sustainable packaging system. For improving the quality, safety, and prolong the shelf-life of the food, ginger essential oil can be incorporated into packaging materials [26, 27]. Chaijan et al. [28] observed an increase in shelf-life of Asian sea bass steak during chilled storage from 8 days for control sample to 15 days for the meat coated with whey protein isolate-polyphenol, containing phenolic extract from ginger, mostly due to the antimicrobial activity of ginger extract.

Zhang et al. [21] investigated the preservation of fresh beef using active coating by agar/sodium alginate film containing ginger essential oil. According to the results of lipid oxidation and antimicrobial assays, the coating extended the shelf-life of the chilled beef by 9 days compare to the uncoated sample (control). Addition of ginger essential oil to the agar/sodium alginate film not only reduced microorganism growth and inhibited lipid oxidation but also delayed the oxidation of myoglobin in meat tissues through acting as a barrier between the beef sample and the oxygen presence in the environment. It is worth mentioning that, the color of uncoated meat changed to brownish red, while the color of the chilled meat did not changed. Amalraj et al. [26] reported synthesis of polyvinyl alcohol/gum Arabic/chitosan film incorporated with ginger essential oil through solvent casting methods. In fact, addition of ginger essential oil to the film, improved its resistance to breakage, increased heat stability of the film, and showed antibacterial activity against pathogens like *Bacillus cereus, Staphylococcus aureus, Escherichia coli*, and *Salmonella typhimurium*.

Direct application of essential oils in packaging films is limited owing to their poorly solubility nature in water, as a common used solvent [29]. Moreover, most ingredient of essential oils may be oxidized and deteriorated when exposed to light, heat, and atmospheric oxygen [26]. The encapsulation of essential oils could solve such problems. In fact, through encapsulation, not only the bioavailability of the encapsulated ingredients increased but also enable controlled release of the bioactive compounds. In addition, intense flavors and odors of essential oils would be minimized [30]. Silva et al. [31] investigated the encapsulation of ginger essential oil at concentration of 12% (v/v) in the ultrafine fibers composed of soy protein isolate, polyethylene oxide, and zein through electrospinning for preservation of fresh Minas cheese. Based on antibacterial assays, addition of ginger essential oil to the composite fibers resulted in decrease in the growth of *Listeria monocytogenes* from 4.39 log CFU/g for control (fiber less package) to 3.62 CFU/g for stored cheeses in the package containing ginger essential oil and fiber after 9 days storage.

Taken together, owing to antibacterial and antioxidant properties, essential oils extracted from ginger can be used directly in various food products as natural food additive for preservation of lipid from oxidation and retardation of bacterial growth. Besides, indirectly application of ginger essential oil for food preservation could be carried out through incorporation of ginger essential oil into packaging material.

3. 2. Meat Tenderization Meat constituents are connective tissue like collagen and elastin, as well as myofibrils composed of four main proteins including myosin, actin, tropomyosin, and troponin. The hard texture of meat is related to the arrangement pattern and chemical structure of these proteins [32]. In tenderization process, degradation of the structural proteins of meat and collagen is carried out in order to reduce meat toughness.

Various mechanical (physical), chemical, and enzymatic methodologies have been employed for the meat tenderization [32]. In this context, exogenous proteolytic enzymes from plant sources like papain, bromelain, and ficin have been demonstrated meat tenderization activity [33]. In fact, exogenous proteases have the potential to digest connective tissue and myofibrillar proteins [25].

Ginger (*zingiber officinalae*) is a potential source of plant proteolytic enzyme. Ginger extract proved meat tenderization activity through hydrolysis of structural myofibrillar proteins and connective tissue, mainly of collagen [33]. The main protease responsible for the tenderization properties of ginger extract is zingibain [32]. Zingibain or ginger protease is a thiol proteinase with a molecular weight of 33.8 kDa. It has optimal proteolytic activity at 60 °C and pH 7 [34]. This proteolytic enzyme was isolated for the first time from ginger rhizome by Thompson and his co-workers in 1973 [35]. It is worth to be mentioned that, ginger proteases contained two main isoforms including GP-I and GP-II [36]. These two isoforms are 83% similar in amino-acid sequence, having homologies with papain [24].

It is well demonstrated that ginger extract has specific proteolytic activity against collagen as meat connecting tissue protein [32, 33]. Addition of ginger extract to camel meat burger patties [25], *M. pectoralis profundus* isolated from the beef brisket cut [33], and tough buffalo meat [35] led to increase in collagen solubility and noticeable reduction in shear force values; consequently, an increase in the tenderness. In fact, to break the meat samples with less resistance to cutting, low shear force is needed. Cruz et al. [37] reported 37.7% reduction in the shear force of chicken breast meat by addition of 5% ginger extract, indicating significant changes in the sample tenderness.

Myofibrillar fragmentation index (MFI) is a useful indicator of meat tenderization associated with the proteolysis of myofibrillar protein [36]. Through enzymatic tenderization, breakdown of Z-lines of meat resulted in reducing the length of myofibril and consequent increase in MFI value [36]. Owing to the proteolytic activity of ginger extract, the MFI value of chicken breast increase from 23.82 to 76.5 for the control (without extract) and treated sample with 5% of crude enzymatic ginger after 24 h storage at 4 °C, respectively [37]. He et al. [36] also reported 23% increase in MIF value of the marinated duck breast muscles with 30% ginger extract in compare to control (no extract) after 72 h of margination, mostly due to the degradation of myofibrillar proteins.

A comparative study was conducted by Naveena et al. [35] on the tenderization properties of cucumis extract, ginger extract, and papain against tough buffalo meat. In compare to control sample (no enzymatic treatment), significant increase in collagen and myofibrillar protein solubility, and reduction in shear force was reported for all enzyme-treated meats. Meanwhile, the sample treated with ginger extract demonstrated better flavor, appearance and tenderness. Besides, higher cooking yield was observed using ginger extract and papain compare to cucumis-treated meat.

In summary, ginger's protease enzyme could be used as an alternative of the most popular commercial enzyme like papain in meat tenderization. From the above section, it can be concluded that incorporation of zingibain with meat product not only enhances the tenderness, but also has the ability to improve the flavor and juiciness of meat products.

3. 3. Pharmaceutical Applications Ginger rhizome has a long history of application in traditional medicine for its performance in stopping vomiting and bleeding, acting as diaphoretics, and treating phlegm/cough [13]. Extract from ginger demonstrated therapeutic potential to ameliorate various disorders such as atherosclerosis [38], metabolic dysfunction (e.g. diabetes) [13], cardiovascular, gastrointestinal symptoms [15], treating vascular disorders (e.g. hypertension), and bone disorders (e.g. rheumatoid arthritis) [13].

Modern science revealed ginger extract composed of valuable bioactive compounds like terpenes, polysaccharides, lipids, phenolic, and organic acids [15]. Multiple biological activities associated to these bioactive compounds have been reported for ginger, including anti-inflammatory, anti-rheumatic, antibacterial, antifungal, hypolipidaemic, anti-obesity, anti-carcinogenic (e.g. lung, liver, ovarian, pancreatic, and colon cancer), and strong antioxidant activity, as well [9, 39-41].

Bernard et al. [42] compared the ability of bioactive components of ginger rhizome extract, including [6]-gingerol, [8]-gingerol, and [10]-gingerol in inhibition of human and mouse mammary carcinoma cells growth. Based on reported results, the [10]-gingerol was more effective than [6]-gingerol and at least as potent as [8]-gingerol in inhibition of human (MDA-MB-231, MDA-MB-468) and mouse (4T1, E0771) cell growth. In fact, the growth of MDA-MB-231 cells was influenced by the inhibitory effect of [10]-gingerol that reduces the number of rounds of cell division and induction of apoptosis through mitochondrial outer membrane permeabilization.

To inhibit the generation of oxidative stress and consequent occurrence of diseases such as cancers, diabetes, and cardiovascular, the balance between antioxidant molecules and free radicals is necessary. In fact, antioxidants act as free radical scavengers through chemical prevention of electron transformation from other molecules to the free radicals [43]. Zingerones, which belongs to pungent constituents of ginger suppressed the oxidative stress through the addition of C=O at the C_3 position [13]. Ginger extract also demonstrated antioxidant protective affects against BPA-induced thyroid oxidative damage through increasing the synthesis of thyroid hormones and activating the expression of Nrf-2/HO-1 gene [44].

The pharmaceutical properties of ginger extract are mostly related to its phytochemicals such as 6-gingerol, 8-gingerol, 10-gingerol, and 6-shogaol [45]. Fajrin et al. [46] revealed the role of 6-shogaol in alleviating hyperalgesia and allodynia in painful diabetic neuropathy in a mice model. Another work performed by Simon et al. [47] used a parallel artificial membrane permeability assay to investigate the effect of ginger extract on the central nervous system. Their results demonstrated that 6-gingerol, 8-gingerol, and 6-shogaol are able to penetrate blood-brain barrier through passive diffusion. This finding support the fact ginger extract possesses anti-neuroinflammatory activity *via* prevention of neurodegenerative diseases like Alzheimer's and Parkinson's [47].

Contaminated food and feed with Aflatoxin B_1 is the main causes of hepatocellular carcinoma [48]. The phenolic rich extract from ginger, mostly composed of 6-gingerol and 6-shogaol, exhibited hepatoprotective activity in treatment of Aflatoxin B_1 induced toxicity of liver through reducing lipid peroxidation along with improving the activities of antioxidant enzymes [48]. Moreover, the bioactive compounds of ginger extract like 6-gingerol, 6-shogaol, 6-paradol, and zingerone were found effective in treatment of age-related neurological disorders. In such disorders, the risk of diseases increases with aging *via* modulating signaling molecules of cell death or cell survival (e.g. stroke, multiple sclerosis (MS), migraine, and epilepsy) [13].

In brief, ginger possesses active compounds with therapeutic potential in various diseases mostly due to their antibacterial activity and efficiency as reducing oxidative stress.

3. 4. Corrosion Inhibitor

Corrosion is a natural process in which alloys and metals interact with certain elements presence in their surroundings to form more stable compounds named as corrosion product [49]. In this process, loss of metal happen and the surface of metals become corroded [50].

Metals, with the exception of gold and platinum are found in nature in impure form mostly as oxides or sulfides, in stable state. For having pure metals, energy is consumed which lead to the formation of pure metals that are in higher energy state than the ore, in unstable state. So, corrosion is the easiest and fastest way for unstable metals to reach to the lowest energy state with stable thermodynamic form [51]. Different factors like temperature, acidic or bases environment, hazardous gases, salts, moisture, and formation of bacterial biofilm on the metals and alloys surface accelerate the corrosion phenomena [50, 51]. Use of corrosion inhibitors is an effective, economic, and convenient strategy to minimize corrosion related issues in many systems such as boiler, oil and gas production units, cooling systems, and refinery units [52].

Electrochemical analyses revealed the inhibitory function of ginger extract as green biocide in reducing chloride-induced corrosion of reinforcing steel. As the chloride threshold value (CTV) improved from 0.02 mol/L to 0.08 mol/L by using ginger root extract at optimum dosage of 2% [53]. Another work performed by Gadow and Motawea [54], investigated the effect of concentration and temperature on the inhibitory activity of ginger extract against corrosion of carbon steel in HCl (1M) solution. The results of weight loss (WL) measurement of carbon steel in 1M HCl solution revealed the positive effect of rise in concentration of ginger extract as inhibitor on inhibition efficiency (IE), as the WL reduced by increasing the concentration of ginger extract. On the other hand, high temperature demonstrated negative effect on IE. According to the reported results, the IE reduced from 94.9 to 62.8% at temperature of 25 °C and 55 °C, respectively [54]. This phenomena could be related to the fact that the electrostatic force that induce adsorption of plant extract on metal surface weaken at high system temperature [51].

The presence of water along with bacterial biofilm formations are two important reasons for the corrosion of materials in cooling towers systems. In fact, microorganisms provide an electrolytic environment that stimulate the anodic or cathodic reaction, causing metal surface corrosion [55]. Use of ginger extract, the WL value of mild steel 1010 in a cooling water system reduced from 992 mg (control sample) to 41 mg. Ginger extract at optimum concentration of 20 mg/L showed 80% IE on microbial corrosion of mild steel in the cooling water system. This can be explained by the fact that, ginger extract with high antibacterial activity prevented bacterial growth on metal surface. In addition, ginger extract affected on the composition of extracellular polymeric substances produced by the bacteria. As, by using ginger extract as inhibitor, the amount of protein and carbohydrates formed in the biofilm on the metal surface decreased from 44% and 18% to 27% and 9%, respectively [55].

Plant extracts as natural corrosion inhibitors composed of various phytochemicals like flavonoids, alkaloids, phytosterol, tannins, glycosides, and phenolic compounds with polar functional groups such as amino, ester, hydroxyl, carboxylic acids, and amid which facilitate their adoption on metal surface [56]. The above mentioned bioactive molecules can be served as the center of interaction with the surface of metals [51, 57]. In corrosion inhibition process using inhibitors, the adsorption of inhibitors onto the metal surface decreases the diffusion rate of reactants, consequently; reducing metal corrosion rate [52]. In fact, the interaction between inhibitor and heteroatoms of metal surface like sulphur, nitrogen, phosphorous, and oxygen led to the blockage of binding sites on the surface of metal [55]. According to Figure 3, the presence of phenolic constituents and lots of aromatic ring functional groups that contain oxygen atom and π-electrons in ginger extract could possibly be responsible for its inhibitory performance [53, 55].

The inhibition mechanism of plant extract is based on the adsorption including physisorption and chemisorption or both, which named as mixed-type adsorption inhibition mechanism (Figure 3) [50, 51]. The mixed-type inhibitors demonstrated the highest protection owing to the effecting on both cathodic and anodic reactions [50]. According to the literature [53, 54, 59], ginger extract was classified as a mixed-type corrosion inhibitor, demonstrating inhibition effect *via*

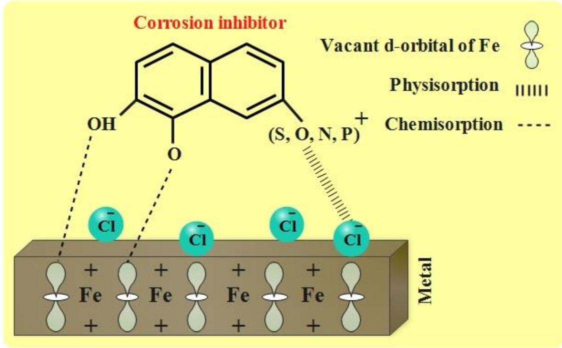

Figure 3. Mechanism of corrosion inhibition by ginger extract; physisorption through electrostatic interaction and chemisorption between heteroatoms of aromatic ring and vacant d-orbital of metal [58]

the formation of carbonaceous organic film on the metal surface. Base on analyses of liquid chromatography-mass spectrometry (LCMS), X-ray photoelectron spectroscopy (XPS), and attenuated total reflection Fourier transform infrared spectroscopy (ATR-FTIR); the carbonaceous film could be composed of different phenolic compounds like 6-gingerol and curcumin [53]. Coordination bonds between oxygen atoms in C=O or N=O bonds of the phenolic constituents and empty d-orbital of metal elements were believed to be as a mechanism of ginger extract adsorption on the steel surface (see Figure 3). As a result, the corrosion reactions of both cathodic and anodic areas were restrained [53, 59].

In short, corrosion is harmful to the human health and environment. Ginger extract as a green inhibitor can control and prevent corrosion. It possesses numerous phenolic compounds that enable its adsorption on metal surface, acting as a barrier for biofilm formation through blocking the binding sites on the surface of metal.

3. 5. Biodiesel Preservation Biodiesel is a biofuel that is generated from nonpetroleum sources. In fact, it is short-chain alkyl (methyl or ethyl) ester produced *via* the transesterification of fats and vegetable oils as renewable energy sources in the presence of appropriate catalyst [60]. In compare to diesel obtained from fossil fuels, biodiesel demonstrated negligible toxicity with low contents of sulfur and aromatic hydrocarbon. However, owing to the presence of allylic and bis-allylic groups in the chains of fatty acid esters in oil feedstock, which is used for biodiesel production, biodiesel faced the problem of oxidation degradation during long-term storage [61].

Factors like light, heat, transition metals, water, and presence of oxygen can cause fuel oxidation during storage [62]. As a consequence, the quality of biodiesel reduced due to the changes in fuel properties like increasing its viscosity, acidity, and water content which can damage the engine [63].

Use of antioxidant additives is an efficient method for preventing or delaying the oxidation of biodiesel during long storage periods. For improving biodiesel oxidation stability, natural antioxidants are better choice in compare to synthetic antioxidants owing to the biodegradability and nontoxicity [60]. In this context, ginger extract as a green antioxidant has potent to improve the quality of biodiesel by increasing its oxidative stability [62]. In fact, owing to the presence of high non-polar compounds in ginger extract as well as low water content, it has good miscibility in biodiesel for acting as an natural antioxidant [1].

The oxidation stability of biodiesel can be determined by induction period (IP). The IP is known as the time of delay, from the beginning of oxidation upon sudden increase in oxidation rate [64]. Devi et al. [1] investigated the effect of different concentrations of ginger extract on IP value of biodiesel obtained from *Pongamia pinnata* oil. The IP of *Pongamia pinnata* biodiesel increased from 4.03 h (without ginger extract) to 17.24 and 23.99 h after addition of ginger extract at concentration of 1000 and 2000 ppm to the *Pongamia pinnata* biodiesel, respectively.

It is worth mentioning that, by addition of ginger extract at concentration of 250 ppm (IP of 8.01 h) complied with American (ASTMD-6751) and European (ENE 14214) standard specifications for oxidation stability of biodiesel.

According to the reported results, ginger extract demonstrated antioxidant activities in a concentration dependent manner in preservation of *Pongamia pinnata* biodiesel. As oxidation stability of biodiesel enhanced at higher percentages of ginger extract. This phenomenon could be attributed to the presence of more number of –OH groups in ginger extract at high concentration. These –OH groups can block or retard the formation of free radicals; consequently, increasing the IP value of biodiesel sample. The overall probable mechanism of 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals scavenging by ginger extract is illustrated in Figure 4. In this process, the lipids oxidation chain reactions of free DPPH radicals stopped by donating hydrogen atoms from phenolic compounds of ginger extract; consequently, forming stable DPPH [1]. In another work by Rial et al. [62], the performance of dichloromethane extract from ginger on oxidation stability of soybean methyl biodiesel was studied. The IP value of soybean methyl biodiesel increased from 3.8 h (without addition of antioxidant) to 6.1 h using ginger extract at concentration of 1000 ppm during 90 days storage.

Taken together, ginger extract with high content of antioxidant compounds can interface with the biodiesel oxidation process and enhances oxidative stability of this biofuel, which is one of the important criterions for fuel quality determination.

3. 6. Synthesis of Metal Nanoparticles Nanoparticles (NPs) composed of inorganic or organic materials. They are submicron molecules with size-dependent properties [65]. Owing to the advantages of plant-based biomaterials like being cost-effective, biocompatibility, and straight forward preparation process [66], the biologically synthesis of NPs using plant extract is an alternative for the large scale green production of NPs and specially metal NPs [67].

Plant extract contains various bioactive compounds like flavonoids, polyphenols, and other biomolecules that enable them to act as reducing agent for the reduction of metal ions to metal NPs [68]. Besides, plant extract can be used as stabilizing agents to prevent metal NPs agglomeration and oxidation, as well [68].

The mechanism of metal NPs synthesis using metal ions and plant extract in our case ginger extract is shown in Figure 5. In this process, ginger extract contains aromatic compounds including zingiberene, amino acids, vitamins, and protein, as well as phenolic compounds like

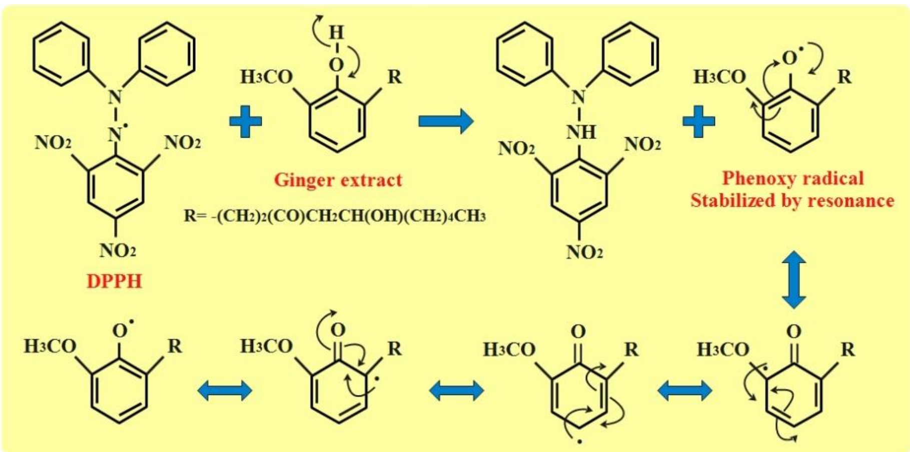

Figure 4. Mechanism of DPPH radicals scavenging by ginger extract [1]

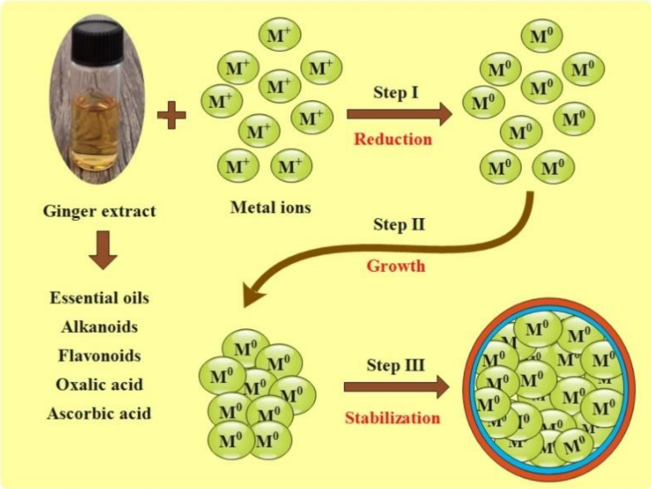

Figure 5. Mechanism of metal NPs synthesis using phytochemicals of ginger extract [70]

6-gingerol and 6-shogaol that acted as both reducing and stabilizing agent. In fact, the mechanism of the formation of metal NPs use of ginger extract could be reduction of metal ions due to the changing enol form to keto form of the alcoholic groups in phytochemicals. Besides, the electrostatic interaction between carboxylic (-COOH) and amine ($-NH_2$) groups of enzyme present and metal ions supports the stabilization of metal NPs [69].

Various exciting studies have been carried out using ginger extract for the synthesis of metal NPs (summarized in Table 1).

Both water soluble and hydrophobic compounds of ginger extract can be used for the synthesis of metal NPs. Kumar et al. [71] demonstrated that the water soluble compounds of ginger rhizome extract including heterocyclic compounds like flavonoids and alkaloids are responsible for the reduction and stabilization of gold (Au) NPs. In addition, ginger rhizome extract possess chemicals like oxalic acid and ascorbic acid that represented as reducing agents in the synthesis of Au NPs and silver (Ag) NPs [72].

A comparative study was conducted by Yaqub et al. [73] on evaluation of anticancer activities of green and chemical synthesized copper (Cu) NPs using ginger rhizome extract and ascorbic acid as stabilizing agents, respectively. Based on the results of transmission electron microscope (TEM), the spherical NPs were synthesized through chemical and green synthesis approaches, with average size of 22.7 and 35 nm, respectively. According to the reported results, the green synthesized Cu NPs demonstrated higher anticancer activity against HeLa and HepG2 cells compared to the chemical synthesized Cu NPs. This could be attributed to the presence of biomolecules such as curcumin, 6-shogaol, 6-paradol, and 6-gingerol on/in the green synthesized Cu NPs.

TABLE 1. Summary of studies on the green synthesized metal NPs using extract of ginger rhizomes

Nanostructure	Synthesis method	Size (nm)	Shape	Application/significance	Ref.
Ag NPs	Bio-chemical reduction	20-51 (D_{TEM})	Spherical	Anti-cancer activity against human colon carcinoma (HT-29) cells with IC_{50}: 150.8 (µg/mL)	[75]
Ag NPs	Ball milling	11-24 (D_{TEM})	Semi-spherical	Catalytic activities in degradation of 4-nitrophenol and methylene blue	[76]
Ag/iron oxide NPs	Co-precipitation	50-150 (SEM)	Hydrocolloids	Antibacterial activities at concentration of 100 (µg/mL) against Gram-positive and Gram-negative bacteria; contrast enhancing in magnetic resonance imaging	[77]
Ag NPs	Microwave irradiation	~10 (D_{TEM})	Spherical	Antibacterial activities against Gram-positive and Gram-negative bacteria	[78]
Au NPs	Bio-chemical reduction	5-15	Semi-spherical	NPs exhibited bio stability and blood compatibility	[71]
Se NPs	Bio-chemical reduction	100-150 (D_{AFM})	Spherical	Antibacterial activity against *Proteus* sp	[79]
Cu NPs	Bio-chemical reduction	20-100 (D_{TEM})	Spherical	Antibacterial activity against *Staphylococcus aureus*	[80]

In case of participation of hydrophobic compounds of ginger extract in the synthesis of metal NPs, Azizi et al. [74] reported one-pot process for the synthesis of zinc oxide-silver core-shell (ZnO-Ag) nanocomposite using essential oils of ginger extract. The essential oils were obtained by hydro-distillation method and were used as a basic medium for the synthesis of ZO NPs. Besides, the essential oil extracted from ginger acted as reducing agent in the formation of Ag NPs from Ag^+ ions. According to the literature, *zerumbone*, *humulene*, and *camphene* compounds in the essential oil of ginger were known responsible for the reduction of Ag^+ ions and synthesis of Ag NPs.

In brief, heterocyclic compounds of ginger rhizome extract, as hydrophilic constituents, can act as reducing and stabilizing agent in the synthesis of metal NPs. In addition to hydrophilic compounds, essential oils of ginger rhizome extract also demonstrated positive effect in metal NPs synthesis by acting as reducing agent. Owing to the presence of bioactive compounds with antioxidant activity in ginger extract, the green synthesized metal NPs showed more anticancer activity in compare to chemical synthesized NPs.

4. CONCLUSIONS

The present treatise reviewed chemical constituents and all potential applications of ginger rhizome. This review revealed the role of ginger rhizome extract in food preservation through acting as an antioxidant agent in protection of lipid and protein ingredients of food from oxidation. The presence of proteolytic enzyme like zingibain in ginger rhizome supports its further application in meat tenderization by hydrolyzing meat structural proteins and connective tissue and consequent reducing shear force in meat cutting. Besides, ginger extract exert promising multiple health beneficial like anticancer and anti-inflammatory owing to its volatile oils. Demonstrating inhibitory effect in metal corrosion by forming carbonaceous organic film on metal surface makes ginger extract as a promising natural mixed type corrosion inhibitor. Acting as a green antioxidant in increasing antioxidation stability of biodiesel was other potential applications of ginger rhizome. Considering the role of both hydrophobic and hydrophilic compounds of ginger rhizome extract as reducing and stabilizing agent in the synthesis of metal NPs, make a claim on its multiple applications.

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Persian Abstract

چکیده

ریشه زنجبیل، که معمولا با نام زنجبیل شناخته می¬شود، یکی از گونه¬های رایج در غذا و طب سنتی است. زنجبیل غنی از انواع ترکیبات آب دوست و آبگریز است که خواص متفاوتی دارند. دارا بودن عطر تازه، طعم تند، و انواع خواص مفید برای سلامتی، و همچنین ارزان قیمت و در دسترس بودن از مزایای ریشه زنجبیل است. علاوه بر جنبه¬های درمانی در طب گیاهی و مصرف به عنوان یک طعم دهنده در غذا، ریشه زنجبیل توانایی بالقوه برای کاربرد در دیگر زمینه¬ها دارد. در این مقاله مروری، انواع کاربردهای زنجبیل، شامل استفاده از آن برای محافظت از غذا و بسته بندی محصولات غذایی، نرم کننده محصولات گوشتی، خواص درمانی، کاربرد آن به عنوان مهار کننده خوردگی فلزات، محافظت از بیودیزل در مقابل اکسید شدن، و نقش آن در ساخت نانو ذرات فلزی مورد بحث و بررسی قرار می¬گیرد. در کل، این مقاله مروری اطلاعات ارزشمندی در مورد ریشه زنجبیل به عنوان یک ماده با منشا گیاهی، علارغم کاربرد آن به عنوان یک گیاه داروی و طعم دهنده فراهم آورده است.