Chapter

Garlic (*Allium sativum* L.): Characterization of Bioactive Compounds and Related Health Benefits

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Abstract

Garlic (*Allium sativum* L.) is one of the greatest gifts of natural medicine and the oldest medicinal herbs that is cultivated all over the world. It is a widely used spice plant with well-known medicinal properties. Garlic is an important raw material of plant origin with observed and proven positive effects on the human body. *A. sativum* L. belongs to the most extensively studied medicinal herbs from genus *Allium*. In the past few decades, its biologically active compounds have been analyzed for their therapeutical properties. The most essential biologically active compound discovered in *A. sativum* is allicin, working synergistically with other phytochemicals in the prevention of many diseases. Preparation of garlic extractions can be done in liquid form and solid form. The composition and bioactivity of the extraction depend on the strain, age, method of preparation, and consumption method. When extracted and isolated, the bioactive compounds of garlic show a wide range of beneficial health effects: platelets inhibitory and antithrombic activities, hepatoprotective, antimicrobial, antihyperglycemic, antidiabetic, and antitumor. The present chapter describes botanical characterization of garlic, its chemical composition regarding bioactive compounds, and its health benefits.

Keywords: scallion, health benefits, polyphenols, antioxidant, sulfur compounds

1. Introduction

The name "*Allium sativum*" is derived from the Celtic word "all" meaning burning or pricking and the latin word "*sativum*" meaning planted or cultivated. Garlic is known by various names, such as "stinking rose", "nectar of the gods", "Russian penicillin", "natural antibiotic", "herbal viagra", "herbal talisman", "snake grass", some names are still used today [1, 2].

Garlic is known to have been used for medicinal purposes as far back as the middle ages, as evidenced by ancient writings from China, Egypt, Greece, and India [3]. Garlic has been used in various cultures for thousands of years, dating back to the time when the Egyptian pyramids and ancient Greek temples were being built. In 1720, garlic was used to save the inhabitants of Marseille from the black plague. Garlic was often used in funerals and religious ceremonies to mummify bodies. The Greeks used garlic as a remedy against aging and disease. Interestingly, Greek athletes participating in the olympic games chewed garlic to improve their stamina, strength, and endurance [4]. In Roman times, workers and soldiers chewed garlic before battle, and the Slavs claimed that it protected them from snakebites. In Africa, fishermen painted their bodies with garlic extract to ward off crocodiles. In Europe, garlic was believed to be able to ward off vampires, demons, evil spirits, and other magical properties. Even the Bible refers to its use [5]. This aromatic vegetable is mentioned in the Bible because the Israelites were tired of eating simple manna and longed for the pleasant varieties that were eaten in Egypt. Garlic has been used among several ancient civilizations around the world in addition to Egypt, Greece, Rome, India, and China to treat various ailments, including poisoning, respiratory and stomach ailments, abnormal growth, headache, insomnia, and depression [6]. The ancient Greek physician Hippocrates (ca. 460–370 BC), known today as the "father of western medicine," prescribed garlic for a wide range of ailments. Hippocrates recommended the use of garlic to treat respiratory problems, parasites, indigestion, and fatigue [7]. Garlic is an effective medicine against diseases, including viral diseases. Ingestion of fresh garlic or intravenous preparation of its extracts has also been used to treat patients with cryptococcal meningitis in China. In Asia and Europe, garlic was used to treat cold, fever, cough, asthma, and wounds. Garlic has been used in traditional African medicine (in Ethiopia and Nigeria) to treat infections, including sexually transmitted diseases, tuberculosis, respiratory tract infections, and wounds [8]. Throughout history, in the Middle East, East Asia, and Nepal, garlic has been used to treat bronchitis, hypertension (high blood pressure), tuberculosis, liver disorders, dysentery, flatulence, intestinal worms, rheumatism, diabetes, and fever [7].

Nicolas Culpeper wrote in the Complete Herbal, 1653, "...a remedy for all diseases and injuries. It induces urine and menses, helps in bites of mad dogs and other venomous creatures, kills worms in children, cuts and destroys tough phlegm, clears the head, helps lethargy, and is a good preservative and remedy for any pestilential, sore, or foul sores." Garlic was already used by the ancient Egyptians for both medicinal and food purposes. Several bulbs of garlic were found in the tomb of Tutankhamun, probably to protect the young king on his way to the afterlife [9].

During World War I, garlic was widely used as an antiseptic to prevent gangrene, and today people use garlic to prevent atherosclerosis, improve high blood pressure, and relieve coughs and bronchitis [10]. Garlic has attracted special attention in modern medicine because of the widespread belief in its effects on maintaining good health. In some western countries, sales of garlic preparations are comparable to prescription drugs [11]. The main garlic growing countries are China, India, Spain, Egypt, Argentina, Italy, and the United States [12]. Currently, China is the largest producer and exporter of garlic [6].

Multiple studies have shown the multifaceted health effects of garlic, which is why it is recommended as a dietary supplement all over the world. Because of these proven effects, its consumption has increased, especially in the culinary field [13]. Replace the entirety of this text with the introduction to your chapter. The introduction section should provide a context for your manuscript and should be numbered as first

heading. When preparing the introduction, please bear in mind that some readers will not be experts in your field of research.

2. Chemical composition of garlic

Garlic is considered one of the 20 most important vegetables with various uses around the world, either as a raw vegetable for culinary purposes or as part of traditional and modern medicine [14].

Its health-promoting properties are attributed to its chemical composition. The chemical composition of garlic is significantly influenced by the variety, growing conditions, and growing practices. In particular, the fertilization regime and soil properties can have a significant impact on quality properties, such as mineral composition, dry matter, protein content, and total soluble solids content [15]. Due to the fact that garlic is commonly consumed cooked and as a dried spice, several authors have also investigated and found that heating can affect the chemical composition of garlic, including its antioxidant properties. The health benefits of garlic depend on the content of biologically active compounds that differ between varieties and geographical areas [16].

Fresh garlic contains approximately 63% water, 28% carbohydrates (fructans), 2.3% organosulfur compounds, 2% protein (allinase), 1.2% free amino acids (arginine), and 1.5% fiber [1, 17]. Other authors [18] reported approximately 65% water, 28% carbohydrates, 2.3% organosulfur compounds, 2% protein, 1.2% free amino acids, and 1.5% fiber in garlic.

Garlic contains 17 amino acids, which include lysine, histidine, arginine, threonine, aspartic acid, glutamine, proline, serine, glycine, alanine, cysteine, valine, methionine, isoleucine, leucine, tryptophan, and phenylalanine. A very effective component of garlic is polysaccharides, which are becoming more and more attractive due to their various pharmacological effects. They exhibit various biological activities, including antioxidant and hepatoprotective effects. Garlic polysaccharides consist of monosaccharides, such as fructose, glucose, and sucrose [19]. These polysaccharides have a high molecular weight, form one of the active components of garlic, and are characterized by low toxicity. In garlic, they represent approximately 26–30% of the fresh weight [20].

Study [21] reported that the main carbohydrate in kitchen garlic is sucrose, which ranged from 1.99 to 3.29 g.100 g-1 fresh mass and represented up to 97% of the total carbohydrate content in garlic. Fructose was detected in relatively low amounts, and glucose was not recorded in the monitored garlic varieties. Dried garlic heads contain mainly water (62–68%) and carbohydrates (26–30%), while proteins are detected in a relatively smaller amount (1.5–2.1%). The energy content is approximately 140 kcal.100 g-1 of fresh mass.

Garlic contains a high content of vitamins, especially vitamin C and group B vitamins. Vitamin C has beneficial effects on the immune system. Ensuring sufficient intake of vitamin C through the diet is essential for the body's resistance to infections [22].

Garlic contains relatively large amounts of vital minerals and trace elements, such as calcium, phosphorus, potassium, sodium, magnesium, aluminum, iron, copper, manganese, chromium, molybdenum, selenium, germanium, and iodine. The most represented minerals in garlic are potassium, phosphorus, and calcium [23]. Other authors [24–26] state the rich content of sodium, magnesium, potassium as well as vitamin C and group B in garlic. Potassium is one of the main blood minerals called

electrolyte, it is important for cellular function; a high concentration of potassium helps to prevent hypertension [27].

The health effects of garlic depend on the level of some mineral elements, such as Se, K, Zn, and Ca [28]. Lee et al. [29] reported that potassium, phosphorus, magnesium, and calcium are the main constituents of garlic. Sulfur, selenium, and germanium are also found in kitchen garlic [30].

Turan et al. [31] reported that consumption of 100 g of garlic represents 3–5% of the recommended daily intake of Zn and Mn for adults. Mineral elements prevent various diseases, such as osteoporosis, cardiovascular disease, and aging.

The vitamins and minerals found in kitchen garlic are essential for proper functioning and health, so they must be obtained through an adequate balanced diet. They are considered micronutrients and act mainly as cofactors [32]. Garlic is an important source of nicotinic acid, thiamin, and riboflavin. It also contains citral, linalool, geraniol, α-phellandrene, valeraldehyde, and propionaldehyde [33]. A wide range of other organic compounds in garlic, such as steroid glycosides, essential oils, lectins, prostaglandins, adenosine, glycolipids, and phospholipids are reported [34].

Garlic is a source of other nonvolatile phytonutrients with significant medicinal and therapeutic properties, of which special emphasis is placed on flavonoids, saponins and sapogenins, phenolic compounds, nitrogen oxides and amides, and proteins [35].

2.1 Sulfur compounds in garlic

The specific smell and taste of garlic caused by sulfur-containing phytochemicals [36, 37]. The most characteristic volatile and odorous organosulfur compounds of garlic are released after disruption of the cell membrane. Garlic contains bioactive compounds, such as organic sulfur compounds, phenols, and saponins, which exhibit various biological activities, namely antioxidant, immunomodulatory, anti-inflammatory, anticancer, hepatoprotective, cardiovascular protective, antidiabetic, antiobesity, renal, neuroprotective, antibacterial, and antifungal activities [38–40]. The synergistic interactions between the individual components present contribute to these remarkable health effects of garlic [41].

Garlic contains at least 33 sulfur compounds. Organosulfur compounds are effective scavengers of free radicals. A unique group of plants of the genus Allium are alk(en)yl-cysteine sulfoxides, which are responsible for their typical smell and taste. These sulfoxides include S-methyl-L-cysteine sulfoxide (methine), S-allyl-L-cysteine sulfoxide (alliine), S-propyl-L-cysteine sulfoxide (propiine), S-ethyl-L-cysteine sulfoxide (ethiine), and S-butyl-L-cysteine sulfoxide (butyin) [42, 43]. Untreated fresh garlic also contains high amounts of glutamylcysteine. These compounds can be hydrolyzed and oxidized to form alliin. In fresh garlic, alliin is present in the amount of 10 mg/g, while in dried garlic its level is 30 mg/g [44].

After processing, such as cutting, crushing, chewing, or dehydration, allinase rapidly cleaves cytotoxic cysteine sulfoxides (alliin) to form cytotoxic and aromatic alkylalkane thiosulfinates, such as allicin, which is the main biologically active component of garlic extract. It represents about 70% of all thiosulfinates formed in crushed garlic [45, 46]. According to Ref. [47] uncrushed garlic contains approximately 16 organosulfur compounds, while crushed garlic contains 23 organosulfur compounds. Allicin contributes to the characteristic flavor and aroma of garlic [16]. Allicin is a thio-ester of sulfenic acid and its beneficial effect on health is attributed to its antioxidant activity as well as its interaction with thiol-containing proteins (**Figure 1**) [48].

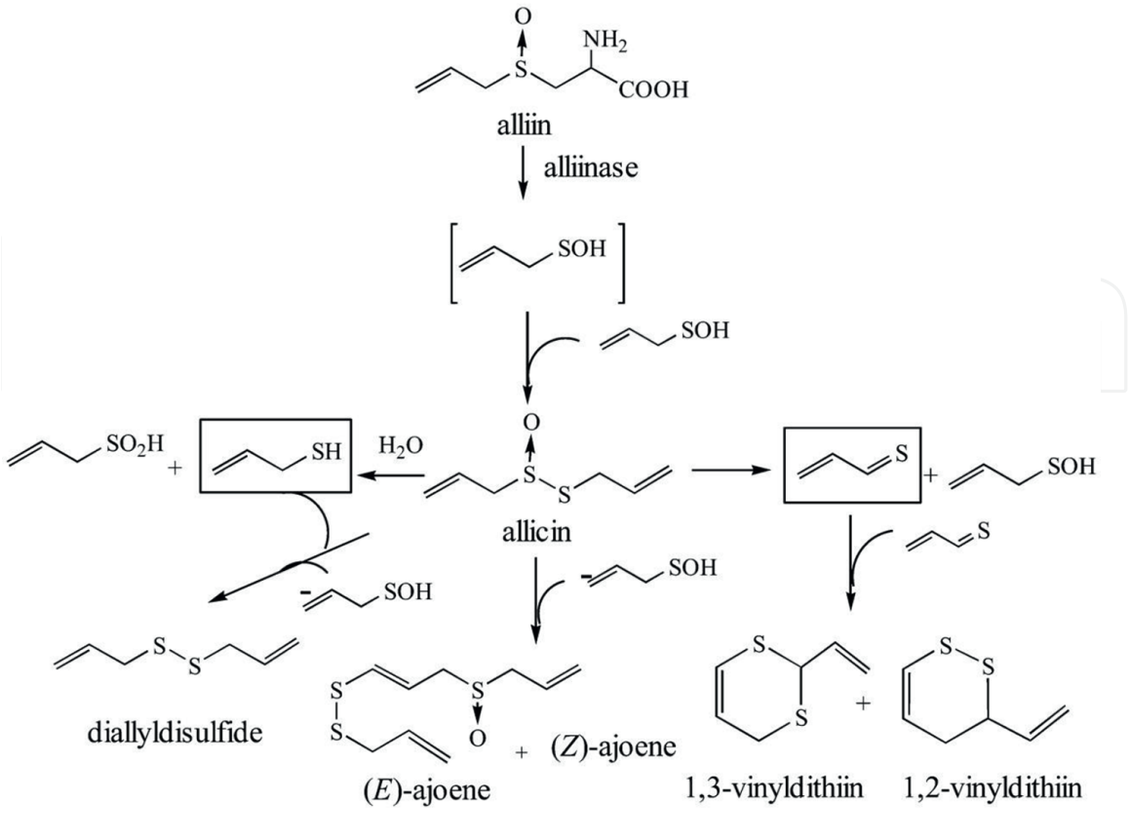

Figure 1.
Enzymatic reaction of sulfur-substituted cysteine sulfoxides. Source: [48, 49].

Garlic also contains S-propylcysteine-sulfoxide (PCSO) and S-methylcysteine-sulfoxide (MCSO). Other sulfur compounds found in garlic include diallyl sulfide, diallyl disulfide, diallyl trisulfide, S-allyl cysteine allyl mercaptan, allyl methyl disulfide, allyl methyl trisulfide and Ref. [6].

These active compounds are mainly responsible for protecting tissue from damage and various disorders [1]. Some phenolic compounds and thiosulfinates are related to the defense function of garlic, and these compounds serve as nonenzymatic antioxidants and antifungal metabolites [50]. These organosulfur compounds are very sensitive and chemically unstable; they are prone to degradation and easily undergo oxidation when exposed to light, oxygen, and high temperatures [40]. The different content of sulfur compounds in garlic varieties is determined genetically [51].

2.2 Polyphenol content and antioxidant activity of garlic

Polyphenolic compounds are a group of biologically active compounds in plant foods. Polyphenolic compounds have been identified as nutrients, plant secondary metabolites, phytonutrients, antioxidants, dietary bioactive substances, and protective factors [52].

Secondary metabolites, such as phenolics, including flavonoids and anthocyanins, have been shown to be significantly involved in plant responses to various abiotic factors, including temperature [53]. In addition to temperature, the influence of light is also considered to be one of the main influences that affect the biosynthesis of phenols in plants during growth and development. The consumption of polyphenolic compounds may play an important role in health prevention through the regulation

Phenolic acid	mg.kg^{-1} FW
Pyrocatechuic acid	1.7
Caffeic acid	0.06
p-Hydroxybenzoic acid	0.05
p-Coumaric acid	2.1
Ferulic acid	4.3

FW: fresh weight.

Table 1.
Content of phenolic acids in garlic [55, 56].

of metabolism, weight, chronic diseases, and cell proliferation. Kitchen garlic (*Allium sativum* L.) is one of the important vegetables, which is characterized by a significantly high content of polyphenolic compounds that has a positive effect on the human body. The largest share of polyphenolic compounds in garlic is represented by phenolic acids and flavonoids. Garlic is ranked second in total polyphenol content out of 23 commonly consumed vegetables [54]. Phenolic acids are among the most important antioxidants that protect the human organism against the negative effects of free radicals (**Table 1**) [55, 56].

Among the phenolic acids in garlic, caffeic acid, o-, m-, p-coumaric acid and chlorogenic acid, were identified. Of the derivatives of hydroxybenzoic acids, mainly gallic acid, protocatechuic acid, β-resorcylic acid, vanillic acid, and syringic acid. Of the other phenolic substances, mainly pyrogallol, rutin, hesperidin, resveratrol, and naringenin were identified in garlic [34]. Garlic flavonoids, such as nobiletin, tangeretin, and rutin, also significantly contribute to the pharmacological activity of garlic (**Table 2**) [57].

Beato et al. [54] mentions the presence of caffeic acid, ferulic acid, vanillic acid, p-hydroxybenzoic acid, and p-coumaric acid in garlic. Colorful varieties of garlic are rich in anthocyanins. The antioxidant properties of garlic are widely proven. Some polyphenols and sulfur-containing compounds are antioxidants and participate in protecting cells from oxidative damage. Garlic oil has been found to contain more than 30 organic sulfur-containing compounds, including diallyl trisulfide, diallyl disulfide, and diallyl sulfide with excellent antioxidant properties [58, 59]. Anwar et al. [60] attributes the antioxidant activity of garlic to organosulfur compounds that increase glutathione levels and glutathione-S-transferase activity. Garlic oil contains compounds based on sulfhydryl groups (–SH) that directly trap ROS and modulate the redox state of cells.

Flavonoid	mg.kg^{-1} FW
Total flavonoid content	36.1
Quercetin	1.74
Myricetin	1.61
Kaempferol	0.26

FW: fresh weight.

Table 2.
Content of flavonoids in garlic [56, 57].

Bozin et al. [61] describe a strong relationship between the content of polyphenolic compounds and the value of antioxidant activity in cooking garlic. The collective of authors [62] analyzed the correlation between the content of total polyphenols and antioxidant activity in 43 varieties of garlic and showed significant positive correlations. Consumption of garlic has antioxidant and antigenotoxic properties, which demonstrates a chemopreventive role against the harmful effects of hydrogen peroxide [63].

3. Health benefits of garlic

The phytochemicals found in garlic exhibit several biological effects, play a key role in maintaining health and have the potential to reduce the risk of civilization diseases. The pharmacological effects of garlic on human health are in a certain correlation with the content of bioactive compounds present in garlic. Garlic preparations, such as oils, powders, and pills, are already widely used in several cardiovascular diseases, as they effectively reduce blood lipid profiles and blood pressure [64, 65]. Antibacterial properties were first attributed to garlic by L. Pasteur. Hippocrates already observed that garlic inhibited cancer cell lines and also prevented intestinal diseases [66].

Garlic extracts are characterized by antioxidant, antidiabetic, antimicrobial, antiasthmatic, and neuroprotective effects [36, 67]. Shang et al. [68] describes the anticancer, hepatoprotective, antidiabetic, anti-obesity effects of garlic. It is known that secondary metabolites as well as organic sulfur compounds, mainly allicin and thiosulfinates, are responsible for most of the biological activities of garlic, such as antibiotic, antiviral, and antifungal properties [69, 70].

Consumption of garlic helps in the metabolism of fats, reduces the level of cholesterol and triglycerides in the blood. *In vitro* and animal studies have shown that garlic can suppress many types of cancer, such as blood, bladder, stomach, breast, oral cavity, lung cancer, colorectal cancer, skin cancer, and uterine cancer [71–73]. Epidemiological studies have shown that garlic has a role in the prevention of cardiovascular diseases due to the presence of these bioactive components [74]. Garlic consumption may protect the brain from loss of intellectual capacity and may reduce the risk of Alzheimer's disease [75].

These properties of garlic are primarily due to the beneficial content of vitamins, phenolic compounds, anthocyanins, flavonoids, and tannins in cooking garlic. Garlic has been shown to have potential anticancer properties, which is due to the content of diverse sulfur-containing compounds that have an inhibitory effect on the carcinogenic process [76]. Choi and Park [77] reported that garlic oil has an anticancer role by inducing apoptosis and inhibiting differentiation and tumor angiogenesis.

Garlic polysaccharides are characterized by antiviral as well as anti-inflammatory effects [78]. Allylsulfides have shown a hepatoprotective effect and improve liver damage. Research has confirmed that diallyl disulfide increases the activity of antioxidant enzymes and reduces lipid peroxidation [79]. Allicin has antimicrobial, anti-inflammatory, antithrombotic, and anticancer properties [46].

Diallyl sulfide suppresses the enzymatic activities of cytochrome P450-2E1, reducing the formation of reactive oxygen and nitrogen species [80]. Studies indicate that diallyl trisulfide (DATS) is responsible for the anticancer effect in garlic consumers, especially organic sulfur compounds, such as peptides of glutamylcysteine, alliin, and their degradation products, which arise when cell membranes are broken, can interact with cytochromes and P-glycoprotein, and can effectively reduce cholesterol levels [81].

Garlic extracts are also effective against *Helicobacter pylori* [82]. Consumption of garlic has been reported to have some beneficial effects in preventing changes in the lipid profile induced by the heavy metals, nickel, and chromium [83].

Ajoene present in garlic has many health benefits. It works as an antioxidant. Ajoene also has antithrombotic properties that help prevent blood clots, which reduces the risk of heart disease and stroke in humans. Ajoene exhibits potential virucidal properties against a range of viruses, including vesicular stomatitis, human rhinovirus, and herpes. Ajoene has a wide spectrum of antimicrobial (antibacterial and antifungal) properties. Ajoene reduces the tumor size of basal carcinoma cells by inducing apoptosis, it is effective in inhibiting the growth of tumor cells [84]. Regular consumption of garlic may have a chemo-preventive role against various human cancers including colon, liver, breast, stomach, and pancreatic cancer. Garlic polyphenols lower blood glucose levels in a variety of ways, such as preventing β-cell damage, reducing insulin resistance, increasing insulin sensitivity and secretion, and suppressing the activity of glucosidase enzymes. Bioactive substances found in garlic suppress lipid peroxidation, nitric oxide synthetase activity, alleviate cardiovascular complications, allergic reactions, and delay aging [66]. Garlic oil inhibits proliferation and induces apoptosis in a pancreatic cancer cell line [85].

4. Conclusions

Garlic has been considered a source of highly promising functional foods and traditional herbal medicine for millennia. Overall, garlic is an excellent natural source of bioactive sulfur-containing compounds and has promising applications in the development of functional foods and for the prevention and treatment of some diseases. Garlic (*A. sativum* L.,) is most important vegetable in agriculture, food industry, and gastronomy that has been widely utilized as flavoring, culinary, and in herbal remedies and seasoning. The consumption of traditional plants, especially garlic has progressively increased worldwide because of their great effectiveness, fewer side effects, and relatively low cost. Garlic is well known to contain various phytochemicals. These compound play key role in maintaining human health and having potential to reduce many diseases. It has distinct nutritional profile with special reference to its various bioactive components that can be used in different diet-based therapies to cure various life-style related disorders and also in developing of foods with added values.

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Conflict of interest

The authors declare no conflict of interest.

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