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# Garlic (*Allium sativum* L) and Its beneficial properties for health: A Review

## El ajo (*Allium sativum* L) y sus propiedades beneficiosas para la salud: Una revisión

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## ABSTRACT

Generally, chefs use garlic as an ingredient that enhances the sensory qualities of foods. However, recent studies have shown that garlic contains Sulphur compounds, which provide a health benefit. This review identifies and describes those constituents in garlic responsible for their anti-microbial, antioxidant, anti-inflammatory, and in some cases anti-cancer properties. Also, this review reports the chemical and nutritional contents of garlic (*Allium sativum* L.) and shows its health benefits for humans. A large variability and diversity in the nutritional content of garlic was found in the literature, including functional properties (antioxidant, antimicrobial, antifungal, and immunological), and many health benefit components, such as antihypertensive, hypolipidemic, antiatherogenic, anticarcinogenic, antitumor, antiaggregant, fibrinolytic, immunomodulatory, and antianemic. Allicin and ajoene were identified among some of the compounds in garlic which are beneficial for human health. Quantity varies depending on bulb maturity and harvest location, and values range between approximately 1mg/g and 9mg/g for allicin and 0.12 mg/g to 0.22 mg/g of garlic oil macerate for ajoene.

**Keywords:** Garlic; nutraceutical properties; allicin; ajoene; antioxidant.

## RESUMEN

Generalmente, los chefs utilizan el ajo como un ingrediente que mejora las cualidades sensoriales de los alimentos. Sin embargo, estudios recientes han demostrado que el ajo contiene compuestos de azufre, que proporcionan un beneficio para la salud. Esta revisión identifica y describe los componentes del ajo responsables de sus propiedades antimicrobianas, antioxidantes, antiinflamatorias y, en algunos casos, anticancerígenas. Además, se informa sobre el contenido químico y nutricional del ajo *(Allium sativum* L.) y muestra sus beneficios para la salud humana. En la literatura se encontró una gran variabilidad y diversidad en el contenido nutricional del ajo, incluyendo propiedades funcionales (antioxidantes, antimicrobianas, antimicrobianas, antimicóticas e inmunológicas), y muchos componentes beneficiosos para la salud, tales como antihipertensivos, hipolipidémicos, antiaterogénicos, anticancerígenos, antitumorales, antiagregantes, fibrinolíticos, inmunomoduladores y antianémicos. La alicina y el ajoene se identificaron entre algunos de los compuestos del ajo que son beneficiosos para la salud humana, las que varían dependiendo de la madurez del bulbo y de la ubicación de la cosecha, y los valores oscilan entre aproximadamente 1 mg/g y 9 mg/g para la alicina y 0,12 mg/g a 0,22 mg/g de aceite de ajo macerado para el ajoene.

**Palabras clave:** Ajo; propiedades nutraceuticas; alicina; ajoeno; antioxidante.

## 1. Introduction

Garlic (*Allium sativum* L) is a bulb belonging to the Liliaceae family, which belongs to the Allium genus (Ramírez-Concepción *et al.*, 2016); to date, it is important from the economic point of view and especially for its nutraceutical properties and its benefits for human health. *Allium sativum* L. is a species native to Central Asia (west of the Himalayas) that was cultivated in China, Mesopotamia and Egypt 5000 years ago, it was brought by the Spaniards, at the end of the XV th century, garlic would enter the American continent as a seasoning (Wu *et al.*, 2015) product. Many members of the genus Allium, including about 700 species, have been recognized as rich sources of biologically active secondary metabolites in addition to their antioxidant properties (Herrera *et al.*, 2014; Upadhyay, 2016).

Garlic is one of the oldest vegetative propagated horticultural crops. The edible part of garlic is its

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fresh bulbs. The bulb, its main body part, is also called the 'garlic head', while each of the bulb's segments is referred to as a 'garlic clove'. Garlic has been used since ancient times not only to flavor foods, but as a medicinal plant (Morales-González *et al*., 2019). Most of its health benefits are due to the presence of allicin molecules (Touloupakis and Ghanotakis, 2010; Varga-Visi *et al*., 2019). The culinary, medicinal, and insecticidal properties of garlic are related to the large variety of molecules it contains, including protein, fat, carbohydrates, fiber, ash, sulfur compounds, essential oils, and minerals such as potassium (K), phosphorus (P), magnesium (Mg), sodium (Na), calcium (Ca), and iron (Fe). Garlic is therefore beneficial to human health, its strong and astringent taste is due to its organosulfur compounds, which have been associated with its nutraceutical properties (Frankel *et al*., 2016).

Research has found that when eaten raw, garlic can be beneficial in preventing some diseases (Baliga *et al*., 2013), such as strains of the common cold (Upadhyay, 2016), some cardio-vascular diseases, and high blood pressure (Shafiur, 2007). Therefore, the spread of information related to the preventive and curative properties of garlic along with its benefits to help fight various diseases and its benefits to human health, have greatly increased the consumption of this species (Fratianni *et al*., 2016).

## 2. Botanical description

Garlic (*Allium sativum* L.) is an herbaceous plant that has an approximately 1 m long fragrant stem divided into 6 to 12 bulblets (garlic cloves) joined by a thin shell, which forms the garlic head. *Allium sativum* L. roots come from the basal section of its disc and can reach a depth of at least 80 cm. Its leaves are long, narrow, and flat closer to the plant base, but cylindrical and pointy at the tip. It has small, whitish-purple flowers. Growing garlic requires heavy clay soil, along with humus and large quantities of water. Plant height of garlic 70-80 cm, leaf number 13-15, bulb weight 50 g, bulb diameter 5 cm, 12-13 teeth, growth period of 250 days in winter sowing and latency duration of 40 days (Wu *et al*., 2015).

## 3. Health benefits

Complementary medicine is gaining importance, mainly in ethnobotany, phytotherapy, and phytochemistry. According to the World Health Organization, 80% of the world population uses plants as primary natural medicine. Garlic has been clinically used in many traditional medical systems since ancient times, mainly for treating and preventing diseases (Baliga *et al*., 2013). As a functional and medicinal food, garlic can be used in many ways-raw (fruit and leaves) and as an extract: oil, granulated, and powdered. Garlic has also been shown to strengthen the immune and anti-tumor systems, and the antioxidant activity of garlic polysaccharide protects the body against the harmful effects of free radicals or hydroxyl (Chen and Huang, 2020; Cheng *et al*., 2020; Upadhyay, 2016). A healthy diet with plenty of functional foods made with garlic has been found as beneficial to human health. Fresh garlic can alter anticoagulant levels in the blood and stimulate activity in all the digestive and respiratory organs (Lee *et al*., 2015). Garlic helps the liver (Abdel-Daim *et al*., 2015) and gall bladder function allium properly; it defends them against gut infections (Gatt *et al*., 2015) and problems caused by the decomposition of intestinal bacteria (Leyva *et al*., 2016). Garlic lowers blood pressure (Cicero and Borghi, 2013) and stimulates the circulatory capacity of the heart. Furthermore, it has antihypertensive, hypolipidemic, antiathero-genic, anticarcinogenic, antitumor, antiaggregant, fibrinolytic, antianemic, antimicrobial, antifungal, and immunomodulatory properties. According to Moneim (2015), treatment using macerated garlic extract can help prevent neurodegeneration by alleviating stress.

The immune system in practically all living beings consists of biological structures and processes inside an organism, protecting it against disease, as well as identifying and killing pathogenic and cancer cells (Chiavarini *et al*., 2015). It is even present in single-cell organisms, such as bacteria, where enzymatic systems provide protection against viral infections. The main function of the immune system is to protect an organism against foreign agents of any nature, such as viruses, bacteria, or extraneous molecules that are not part of the organism's biological structure. Table 1 shows some of the immune properties and related compounds of garlic.

### 3.1. Heart disease

Heart disease, including heart attacks and strokes, is the leading cause of death worldwide. High blood pressure, also known as hypertension, is one of the main causes of heart disease. Various studies show evidence of the benefits of garlic to lower blood pressure in people with hypertension (Baliga *et al*., 2013; Cicero and Borghi, 2013). Garlic has also been shown to lower serum cholesterol (Ried, 2016), which is a high-risk factor

in heart disease. Garlic also contains the element selenium (Se), which can reduce cholesterol levels and help prevent cancer (Johnson, 2018).

### 3.2. Respiratory diseases

The common cold is one of the main reasons people visit the doctor. Generally caused by viruses that can cause fever, headache, myalgia and fatigue, the common cold (Upadhyay, 2016) is treated symptomatically. Antibiotics are not effective in children or adults. Prophylactic use of garlic may decrease the frequency of colds in adults, but has no effect on the duration of symptoms (Fashner *et al.*, 2012). Hypertension is one of the most common conditions found in primary care. Non-pharmacological strategies have been shown to help reduce blood pressure, it has been suggested that dietary supplements such as garlic, lower blood pressure (Oza and Garcellano, 2015). Supplementation with aged garlic extract has been shown to restore vasodilatory response in patients with chronic coronary artery disease. It also inhibits the progression of coronary calcifications (Weiss *et al.*, 2013). For centuries, garlic has been used as a home remedy for different skin disorders, especially warts, corns 1 or other skin and oral diseases. Topical application of garlic can induce severe allergic or irritant contact dermatitis, and patients should be counselled regarding the use of such therapies (Chiriac *et al.*, 2017). In ancient times, garlic (*Allium sativum* L.) was used as medicine and is still part of folk medicine in many cultures. An number of articles have commented on the efficacy of garlic in regulating cardiovascular risk factors (Shafiur, 2007), plasma lipids, stopping lipid peroxidation, stimulating fibrinolytic activity, inhibiting platelet aggregation, mitigating morphostructural changes in the vascular wall (related to aging and atherosclerotic lesions) and lowering blood pressure.

**Table 1**
Garlic's immunological and antibacterial properties

| Functionality | Health benefits | Related compounds | Garlic product | Bibliography |
|---|---|---|---|---|
| Immune system and antibacterial response | Immune system boost | Allicin, alliin and ajoene, alliinase, peroxidase, miracynase, sucrose, glucose, minerals, vitamins, beta-carotene | Fresh garlic, powder and oil | (Goncagul and Ayaz, 2010) |
| | Infection, leishmaniasis | Actin, talin, paxillin | Fresh garlic extract | (Ghazanfari *et al.*, 2006) |
| | Cytotoxicity | Antioxidant | Aqueous garlic extract | (Abid-Essefi *et al.*, 2012) |
| | Bacteria | Phenolic compound | Garlic shell | (Kallel *et al.*, 2014) |
| | Pathogenic microorganisms | Antioxidant, phenolic compounds, minerals | Garlic extract | (Khalid *et al.*, 2014) |
| | Antifungal activity | Alliace | Garlic bulb extract | (Lanzotti *et al.*, 2012) |
| | Microbial | Allicin | Garlic clove | (Pirak *et al.*, 2012) |
| | Blastocystosis | Antioxidant | Garlic | (Abdel-Hafeez *et al.*, 2015) |
| | Immune modulatory | Alliin, allicin, ajoenes, vinyldithiins, and sulfides | Extract | (Batiha *et al.*, 2020) |
| | Gut microbiome | allicin-free garlic | Crushed garlic | (Chen *et al.*, 2020) |
| | Gestational diabetes mellitus | Antioxidant | Fresh garlic black | (Si *et al.*, 2019) |
| | Dyslipidemia and Gut Microbiome Dysbiosis | Organosulfur compounds | whole garlic | (Chen *et al.*, 2019) |
| | Immune modulatory Effects of Glutathione, cardiovascular and inflammation | Sulfur | Aged garlic extract | (Rodrigues and Percival, 2019) |
| | Chemical Burns, treat a plantar wart | Allyl disulfide, diallyl disulfide, allicin | Garlic paste, crushing garlic | (Schimmel *et al.*, 2019) |

Modern science has identified that garlic contains several health-promoting compounds with therapeutic effects in the area of heart disease and cancer. Recent work points to the existence in garlic of many substances, many of which are organosulfur compounds and bioactive properties (García and Sánchez-Muniz, 2000; Martins *et al*., 2016) (Table 2).

**Table 2**
Garlic compounds related to cardiovascular, circulatory system improvement and physiological properties

| Functionality | Positive effects | Related compounds and /or functional properties | Garlic product | Bibliography |
|---|---|---|---|---|
| Cardiovascular system and physiological and protective processes | Atherosclerosis, cardiovascular disease | Organosulfur, free radicals | Raw, aged, aqueous, and powdered extract | (Baliga *et al*., 2013) |
| | Circulatory disease, malaise, insect and parasite infestation | Sulfur compounds | Garlic oil | (Leyva *et al*., 2016) |
| | High blood pressure | Ascorbic acid | Garlic supplement | (Oza and Garcellano, 2015) |
| | Dyslipidemia, hyperglycemia, cardiovascular condition | Antioxidant, sulfur, allicin, thiosulfate, ajoene | Garlic supplement | (Suleria *et al*., 2015) |
| | Atherosclerosis, antidiabetic, antimutagenic, anticarcinogenic | Antioxidant, by-products, tetrahydro beta carboline, phenol | Aged garlic extract slices | (Wang *et al*., 2015) |
| | Vascular endothelial dysfunction and atherosclerosis | Diallyl trisulfide | Natural garlic | (Liu *et al*., 2014) |
| | Cholesterol | Phenol, diallyl sulfur, furancarboxaldehyd S-allyl cysteine, S-allylmercaptocysteine, 1-methyl-1,2,3,4-tetrahydro-beta-carboline-3-carboxylic | Aged garlic extract | (Wang *et al*., 2016a) |
| | Secondary metabolism | Flavin, alliin, S-Allyl-L-cysteine, S-allyl cysteine sulfoxide | Green leaves from garlic foliage | (Yoshimoto *et al*., 2015) |
| | Reduce the blood pressure and prevent oxidative stress | GPH-P (pepsin) y GPH-T (trypsin) | Garlic residuals | (Gao *et al*., 2020) |
| | Vasomotoric | Organic sulfides nitroso-sulfide | Garlic juice | (Berenyiova *et al*., 2020) |
| | Inflammation, Obesity and Cardiovascular Disease | Organosulfur compounds, alk(en)yl-L-cysteine sulfoxides (ACSOs), alliin, alliinase | Garlic bulbs | (Quesada *et al*., 2020) |
| | Inhibited excessive adipogenesis obesity | (1R,3S)-1-methyl-1,2,3,4 tetrahydroβ-carboline-3-carboxylic acid | Methanolic extract of garlic | (Baek *et al*., 2019) |
| | Hepatoprotective Acute hepatic injury | γ-glutamyl-S-allyl-L-cysteines (GSACs) and S-allyl-L-cysteine sulfoxide, (alliin), alliinase, allicin, diallyl sulfide (DAS), diallyl disulfide (DADS), diallyl trisulfide (DATS), and allyl methyl sulfide (AMS), ajoene | Extracts Black Garlic | (Tsai *et al*., 2019) |
| | Hematology and histopathology of liver and kidney | Alliin, allicin, and ajoene (Z and E) | Single-bulb garlic oil extract | (Lestari and Rifai, 2019) |
| | Bioprotective Responses against Cardiovascular Diseases | β-carboline derivatives, organic sulfur compounds | Fresh black fermented garlic | (Zhang *et al*., 2019) |
| | Obesity, diabetes, vascular and metabolic diseases | S-allyl cysteine | Black Garlic Extract | (Amor *et al*., 2019) |

## 4. Chemical and nutritional properties

Some studies have mentioned the properties of plant originating foods which contain nutrients and phytochemicals with antioxidant effects (Sun and Wang, 2018; Wang *et al*., 2016a). The increase in food-related diseases has prompted studies to find the link between food and health; for example, the high consumption of fruit and vegetables has demonstrated health benefits. This has inspired research about the chemical properties (Batiha *et al*., 2020) of these foods. Martins *et al*. (2016) reported that garlic has a high dry matter content (30% to 50%). Volatile essential oils can also be found in garlic, which contain allyl disulfide, a compound that originates from the effect of allicinase breaking down allicin. Research has reported information on phenolic acid and flavonoid components of garlic subjected to different phases of thermal processing. The results of the present investigations showed that heat treatment affected the total content of phenols and flavonoids in garlic (Kim *et al*., 2013b), Studies have revealed the effects of different levels of salinity (1.60, 2.87, 4.14, 5.41, 6.68 and 7.95 dS m-1) in garlic, by determining yield and quality parameters such as total dry matter, total soluble solids, total sugar, total acid, vitamin C and proteins, The values of bulb yield, total sugar and acid content increased to 2.87 dS m-1, while soluble solids and proteins gave the highest values to 4.14 dS m-, 1, Increased salt concentrations also decreased vitamin C values (Turhan *et al*., 2014). Some authors reported nutritional values garlic (*Allium sativum* L.) and its components, nutrient types energy provider carbohydrates 33.06 g Play key roles in the immune system, fertilization, preventing pathogenesis, blood clotting and development Sugars 1 g Sugar good for human health dietary fiber 2.1 g production of healthful compounds, increase bulk, soften stool, and shorten transit time through the intestinal tract Fat 0.5 g Membrane synthsis, tissue Protein 6.36 g Build body tissues vitamins thiamine B1 17% (0.2 mg) synthesis of acetylcholine, carbohydrate metabolsim riboflavin (B2) (9%) (0.11 g) Forms the coenzyme FAD Niacin (B3) 5% (0.7 g) Forms the coenzyme NAD Pantothenic acid (B5) 12% (0.596) Forms conezymes involved in amino acid metabolism vitamin B6 96% (1.235 mg) Coenzyme in many chemical reactions Folate (B9) 1% (3 µg) Induce DNA synthesis Vitamin C 38% (31.2 mg) Promotes protein synthesis trace metals calcium 18% (181 mg) matrix component of bone tissue, cofactors of coagulation enzyme Iron 13% (1.7 mg) constituent of hemoglobin magnesium 7% (25 mg) activates ATPase manganese 80% (1.672) Cofactor of kinases and isocitric decarboxylase Phosphorus 22% (153 mg) contituent of lipids, proteins, nucleic acids, sugar phosphates Sodium 1% (17 mg) membrane transporter zinc 12% (1.16 mg) Co‑factor of enzyme selenium 14.2 µg cofactor of glutathione peroxidase sulfur 16% antimicrobial (Upadhyay, 2016). Garlic (Allium sativum L.) is known for its culinary use and its use in folk medicine (Hanen *et al*., 2012; Martins *et al*., 2016). Studies have shown that the organo-sulfur compound (Varga-Visi *et al*., 2019) diallyl disulfide (DADS) found in garlic (*Allium sativum* L.) attenuates the production of CCL2 induced by TNFα in MDA-MB-231 cells, attenuating tumor cells such as breast cancer (Bauer *et al*., 2015). Studies have shown that garlic can assimilate telurate, an inorganic compound of tea, and telurate is transformed into an amino acid containing Te-, the so-called telluroamino acid (Anan *et al*., 2013). Some of the garlic amino acid compounds are alanine, arginine, asparagine, γ-aminobutyrate acid, glutamate, glutamine, isoleucine, leucine, lysine, phenylalanine, proline, threonine, tryptophan, tyrosine, sugar compounds (β-glucose, α-glucose, sucrose), acids (citric acid, malic acid, formic acid, palmitic acid, sulphonic acid, linoleic acid, caffeic acid, p-coumaric acid, diferulic acid, chlorogenic acid, caffeic acid O-glucoside, coumaroylquinic acid, p-coumaroylquinic acid, coumaric acid, O-glucoside, p-coumaric acid, and caffeoyl putrescine) as well as other compounds such as allicin and allyl organosulfur compounds (Guillamón, 2018; Mendez *et al*., 2011; Varga-Visi *et al*., 2019).

Garlic (*Allium sativum* L.) was used in dairy cattle feed and did not change the properties of milk cheese, but affects the colour, texture and taste of ripened cheese (Rossi *et al*., 2018) for example, Rossi *et al.* (2018) concluded that adding 400 g/day of garlic to the feed of lactating dairy cows highly improved the sensory and rheological characteristics of cheese. Zhang *et al.* (2018) prepared amylose-garlic bioactive component complexes (allicin content 0.49 mg/g of complex), which can be used as stable natural flavor compound systems. Kim *et al*. (2018) suggested that elephant garlic may have applications in the development of a new vinegar product with better taste and quality, as well as potential health benefits. Metabolite analysis suggested that

volatile compounds containing sulphur were less abundant in elephant garlic than in normal garlic.
The chemical and nutritional properties of garlic are affected when fresh garlic is treated by conventional drying methods. Fante *et al.* (2015) reported a decrease in inulin content and increase in the glucose and fructose contents is observed in dehydrated garlic as compared to fresh garlic. Also, when fresh garlic was transformed to black garlic (treatment of the fresh garlic at high temperature and humidity), the contents of nutritional components were significantly affected. The polyphenol content increased with an increase in temperature and decrease in humidity. Some studies reported that keeping the temperature at 75 °C and a relative humidity of 85% for 8 days were ideal for black garlic to get better flavor, greater retention of antioxidant capacity and abundant nutrients, and better quality (Sun and Wang, 2018).

## 5. Functional and nutraceutical properties

The functional and nutraceutical properties of food are an opportunity to improve human health, garlic (*Allium sativum* L) is considered as a more important vegetable, with various uses, either as a raw vegetable for culinary purposes or as an ingredient of traditional medicine and a richer source of total phenolic compounds that contribute to the human diet, in addition to their bioactive properties and organosulfur compounds (Martins *et al*., 2016). A large number of studies have investigated the possible effect of flowering blood pressure from different dietary supplements, and nutraceuticals, mostly antioxidant agents with a high profile of tolerability and safety. In particular, a relatively large body of evidence supports the use of potassium, L-arginine, vitamin C, cocoa flavonoids, coenzyme Q10, controlled-release melatonin, and aged garlic extract (Cicero and Borghi, 2013). The functional benefits of garlic are its antimicrobial activity, anti-cancer and antioxidant activity, improves physical activity, reduces cardiovascular disease, improves immune functions and antidiabetic activity. Recent studies identify the active functional components that provide medicinal benefits, as well as their mechanisms of action, including the best possible ways to consume garlic. Allicin (diallyosulphate) is one of the main organosulphuric compounds in garlic considered biologically active (Shafiur, 2007). Szychowski *et al*. (2018) Garlic (*Allium sativum* L) has a reputation as a therapeutic agent for many different diseases such as microbial infections, hypertension, hypercholesterolaemia, diabetes, atherosclerosis and cancer established bioactive components in aqueous extracts of nine garlic varieties from different countries (Poland, Spain, China, Portugal, Burma, Thailand, and Uzbekistan). These results could help in selecting garlic cultivars that contain significant amounts of active compounds, such as syringic and p-hydroxybenzoic acids in Chinese garlic extracts (values ranging between 0.43 and 14.90 µg/mL, respectively).
The excessive consumption of garlic can cause some problems. Garlic can produce bad breath, bad body odor, as well as occasional allergic reactions. Other adverse effects include stomach disorders, diarrhea, decreased whey protein and calcium, anemia, bronchial asthma, and contact dermatitis.
Heavy metals are naturally found in soils, which are formed by geological processes, such as alteration and erosion of underground geological materials. In addition to parent material, the sources of soil contamination are multiple, and include agricultural and industrial pollution (Addis and Abebaw, 2018). Because many people use garlic as a flavoring agent in food and as medicine for different diseases, one point to consider is the absorption of heavy metals by garlic plants that could then be present in garlic extracts (Popa and Petrus, 2017). However, Addis and Abebaw (2018) showed that heavy metal concentration in the soil at levels of 23.866–32.262 mg/kg for Fe, 137 1–213.4 mg/kg for Zn, 401.8–583.7 mg/kg for manganese (Mn), 52.1–77.3 mg/kg for copper (Cu), 106.6–177.6 mg/kg for cobalt (Co), 87.5–123.5 mg/kg for nickel (Ni), 2.3–2.5 mg/kg for cadmium (Cd), and 13.8–23.2 mg/kg for lead (Pb), respectively, is not harmful for the cultivation of garlic and other agricultural purposes. Moreover, the presence of these metals can affect plant metabolism and decrease ethylene vapors in plant respiration (Addis and Abebaw, 2018; Popa *et al*., 2015).
Medicine and pharmacology have searched for new compounds with similar cancer-resistant characteristics. In this field, natural products are quite relevant, and can be used to treat cancer. Flavonoids are secondary metabolites with anticarcinogenic properties, which may play an important role in future cancer treatments, including curcumin, quercetin, and allicin for management of gastric cancer (Haghi *et al*., 2017). It has been shown that garlic has a specific compound with anticarcinogenic properties. For example, flavonoids are secondary metabolites with anti-cancer, cytotoxic, antibacterial and

antiviral capabilities that can be a natural treatment for coronavirus (Guillamón, 2018; Jin *et al*., 2019; Liu *et al*., 2019; Zhang and Liu, 2020), antifungal, antiprotozoal, anti-inflammatory, and antioxidant properties (Table 3).

Many people who currently suffer from cancer wish to undergo alternative therapies, especially with traditional products and treatments popular in Oriental medicine, such as acupuncture, reishi (Ganoderma lucidum), homeopathy, and diets. The best-known natural products with anticarcinogenic properties are vinca alkaloids (vinblastine and vincristine), which are isolated from the Madagascar periwinkle (Catharanthus roseus) and used to treat diabetes.

One example is pointed out by Alkhatib *et al*. (2017), who assessed the antitumor activity and cardiotoxicity of one nanoemulsion formulated with garlic oil (Doc-NEGO). They found that NEGO has a cardioprotective property and the ability to stimulate antioxidant activities in the heart tissue, and it also has antitumor activity.

**Table 3**
Garlic and its functional and nutraceutical properties

| Functionality | Positive effects in diseases | Related compounds and /or functional properties | Garlic product | Bibliography |
|---|---|---|---|---|
| Anticarcinogen | Tumor necrosis, breast cancer, chemo-preventive agents | Diallyl disulfide | Garlic concentrate | (Bauer *et al*., 2015) |
| | Cancer, anti-inflammatory, antimicrobial, colorectal cancer, diabetes, and hypertension | Vitamin C, total phenols, total flavonoids, free sugars content, antioxidant activity, allicin | Dry garlic | (Bhandari *et al*., 2014) |
| | Prostate cancer, breast cancer, gastric cancer, colorectal cancer, diabetes and hypertension | Sulforaphane, glutathione, isothiocyanates, organosulfur | Garlic | (Frankel *et al*., 2016) (Haghi *et al*., 2017) |
| | Colorectal cancer | Calcium supplement, folic acid | Garlic supplement | (Heine-Broring *et al*., 2015) |
| | Cancer treatment | Allicin, ellagic acid | Garlic | (Khuda *et al*., 2014) |
| | Prostate cancer, lung cancer | Allicin, quercetin, | Garlic supplement | (Lee *et al*., 2015) |
| | Anticarcinogen | Polysulfides, hydrogen sulfide, organosulfur, diallyl trisulfide | Garlic scape, garlic oil | (Tocmo *et al*., 2015) |
| | Inhibition zone, anti-proliferation activity | Antioxidants, allicin, ascorbic acid | Garlic extract | (Fratianni *et al*., 2016) |
| | Inhibit inflammation | S-allyl cysteine (SAC), S-1-propenylcysteine (S1PC) and S-allyl mercapto-cysteine (SAMC) | Aged garlic extract | (Ohtani and Nishimura, 2020) |
| | Cancer, muscle atrophy | Z-ajoene | Crushed garlic | (Lee *et al*., 2019a) |
| | Nephropathy | Diallyl disulfide | Garlic oil | (Lin *et al*., 2019) |
| | Anti-inflammatory | S-allyl- l- cysteine (SAC), SMU-8c | Garlic acid conjugates | (Bi *et al*., 2019) |
| | Liver Cancer | Organosulfur compounds (OSCs), diallyl sulfide (DAS), diallyl disulfide (DADS), diallyl trisulfide (DATS), ajoene | Raw Garlic | (Liu *et al*., 2019) |
| | Esophageal cancer | Organosulfur compounds and flavonoids | Raw garlic | (Jin *et al*., 2019) |
| | Diabetes mellitus | Antioxidants | Garlic peel extract | (Lolok *et al*., 2019) |
| | Inhibition pancreatic cancer | Z-ajoene | Structure of Z-ajoene garlic | (Lee *et al*., 2019b) |
| | Management of cancer | Diallyl sulfide, diallyl trisulfide, ajoene, and allicin | Garlic plants | (Almatroodi *et al*., 2019) |
| | Oral carcinogenesis Salivary aldehyde dehydrogenase, | Alliin | Garlic preparations | (Laskar *et al*., 2019) |

## 6. Protective and physiological properties

The major physiological role of garlic and its antimicrobial, anticancer, antioxidant, immune boosting, antidiabetic, hepatoprotective, antifibrinolytic and antiplatelet aggregatory activity and its potential role in preventing cardiovascular diseases (Santhosha *et al.*, 2013) Various treatments have been found for different types of garlic products. Fresh garlic is the product with the best antioxidant and antimicrobial effectiveness, while natural food additives are better than synthetic ones. Garlic oil contains antioxidant compounds as well as pro-oxidants that produce a number of natural protective substances. These substances intervene in various metabolic processes, practically blocking the harmful effect of free radicals generated in specific situations, such as physical stress, malignant tumors, and bad diet (Kim *et al.*, 2010). Aged garlic inhibits AGEs by 56.4% compared to 33.5% for an equivalent concentration of fresh garlic. extract. Similarly, aged garlic had a high total phenolic content (129 ± 1.8 mg/g) compared to fresh garlic. Aged garlic has more potent anti-glycation and antioxidant properties. compared to fresh garlic extract, which can be used as traditional therapies to prevent diabetes complications (Elosta *et al.*, 2017).

Some phenols and diallyl disulfide, 5 (hydroxymethyl)-2 furancarboxaldehyde, S-allycysteine (SAC), S-allyl-mercaptocysteine were identified. (SAMC), 1-methyl-1,2,3,4-tetrahydro-β-carboline-3-carboxylic acid were identified as potent antioxidants in AGE by GC-MS and UPLC-MS/MS, by soaking aged garlic extract (AGE) (Wang *et al.*, 2015; Wang *et al.*, 2016a). Antioxidants are usually found in food or in the human body in small concentrations compared to oxidizable substrates. The flavonoid content in garlic, for example, is between 8.8 mg/100 g and 2.3 mg/100 g in a fresh sample (Somman and Siwarungson, 2015). Kim *et al.* (2013a) have found that black garlic contains total polyphenols with a minimum of 105.7 mg GAE (Gallic Acid Equivalent)/kg on a dry basis, and total flavonoids with a minimum of 595.4 mg QE (quercetin equivalent)/kg and maximum of 869.9 mg QE/kg on a dry basis quercetin and kaempferol (Haghi *et al.*, 2017) and both its organosulfur compounds (Guillamón, 2018) and chemical precursors (alliin, diallyl sulfide, diallyl trisulfide, and prolyl sulfide) (Bauer *et al.*, 2015; Nieto *et al.*, 2012; Varga-Visi *et al.*, 2019). Petropoulos *et al.* (2018) established an antioxidant content (phenolic compounds) between 8.59 and 44.85 mg GAE/g extract in 11 garlic varieties in Greece; radical scavenging activity was between 2.0 and 20.09 (DPPH, EC50, mg/mL).

The physiological effects of garlic include lowering basal metabolism and reducing metabolism disorders caused by fast absorption carbohydrates. These factors help to strengthen human health by significantly decreasing morbidity and mortality. The inclusion of new approaches and health-protective processes represents a new opportunity for public health, which can broaden and enrich this field of knowledge. Garlic contains compounds that can help remove toxins and parasites, as well as heavy metals, such as mercury and residues of medication the liver cannot process.

### 6.1. Antimicrobial properties

Garlic contains substances that can remove bacterial agents or prevent their growth or spread without damaging the infected organism carrying them. It is basically a type of medicine, as powerful as antibiotics or other chemical agents, to fight these microorganisms. For example, Jang *et al.* (2018) found antimicrobial activities in aged and non-aged garlic extracts; they established that the chloroform extract showed significant antimicrobial activity against Staphylococcus aureus, Salmonella enteritidis, Escherichia coli, Bacillus cereus, or Listeria monocytogens, Garlic (*Allium sativum* L.), and particularly its sulphur compounds, inhibits methanogenesis in vitro (Blanch *et al.*, 2016).

Sulfur compounds, such as allicin and ajoene (Martins *et al.*, 2016), Allicin, the main biologically active component of garlic clove extracts,The results suggest that feeding allicin can ameliorate deltamethrin-induced oxidative stress and might have some therapeutic properties to protect Nile tilapia on subacute deltamethrin toxicity (Abdel-Daim *et al.*, 2015), Some studies evaluated phytochemical components such as alum, vitamin C, total phenol and total flavonoid, free sugar content and antioxidant activity of 19 garlic lines and cultivars The total flavonoid content showed the highest positive correlations with antioxidant activity (r = 0.908), followed by total phenol and vitamin C content. (Bhandari *et al.*, 2014). Early studies reported that 30.9 µg/mL of allicin and 16.6 µg/mL of ajoene are required to inhibit Aspergillus niger and Candida albicans mold by 95%. Other studies mentioned that garlic concentrations between 50 µM and 11.7 µg/mL

are needed to inhibit Paracoccidioides brasiliensis mold growth by 90%, Other studies revealed that pure allicin (6.25 µg/ml and 12.5 µg/ml) is more effective in inhibiting the growth of hyphae cells compared to garlic extract (2 mg/ml and 4 mg/ml) and could be used as an alternative in the treatment of dermatophytosis (Aala *et al*., 2014; San-blas *et al*., 1989; Singh *et al*., 2009)

Recent studies show a significant variation in antioxidant and antimicrobial properties between the various genotypes of garlic mainly due to differences in chemical composition and content of bioactive compounds (Petropoulos *et al*., 2018) measured the antimicrobial activity of garlic extracts (in vitro) and established a minimum bactericidal concentration of 0.3 mg/mL extract for S. aureus, and 0.2 mg/mL extract for Salmonella typhimurium. There was also a minimal fungicidal concentration of 0.05 and 0.15 (mg/mL extract) for C. albicans and C. krusei, respectively, In addition, significant differences were observed between the garlic genotypes tested with respect to antimicrobial properties, while garlic extracts were more effective than positive controls against methicillin-resistant Staphylococcus aureus, Escherichia coli and Proteus mirabilis (Goncagul and Ayaz, 2010; Mbaveng *et al*., 2008; Petropoulos *et al*., 2018)

Antibacterials can have different effects on bacteria, such as preventing their growth on the cell wall, making their cell membrane permeable, as well as damaging the bacterial DNA structure or ribosomes to prevent them from synthesizing proteins that keep them alive. However, it was found that garlic, regardless of the preservation procedure, can be a source of microbian contamination in some products, for example as seen in garlic mayonnaise sauce especially with lactic acid bacteria and Clostridium Sp. Spores (Kłębukowska *et al*., 2015).

## 7. Allicin contents

Allicin molecules are highly unstable and quickly transform into several organosulfur compounds during digestion. Studies have reported concentrations of allicin in raw garlic (20.73 to 24.31 mg allicin g - 1 garlic) Alliinase, the enzyme responsible for converting alliin into allicin, is irreversibly destroyed in the acidic stomach environment (Miron *et al*., 2004; Yoshimoto *et al*., 2015). Allicin (the main biologically active compound in garlic clove extract) is a sulfur compound (Haghi *et al*., 2017) found in garlic, which interacts with the alliinase enzyme. This enzyme has been found in different compartments inside the garlic cell. When garlic is crushed, mashed, or sliced, alliinase acts on alliin and creates allicin, which contains powerful health properties (Chan *et al*., 2013). When a cell is damaged, alliinase and alliin are mixed to create allicin and ammonium pyruvate. Some studies have reported allicin and alliin contents of approximately 0.4% and 0.9%, respectively, in fresh garlic bulbs. The main sulfur compound in both raw and powdered garlic is alliin, which is present in garlic cloves in approximate quantities of 8 g/kg. Research has been conducted on 24 garlic ecotypes taken from the main farming areas of Iran to determine the existence of allicin. Allicin content results varied from 1.61% to 7.45% and depended on the farming zone. Another study showed 1.3% allicin content in dry powdered garlic. Fratianni *et al*. (2016) analyzed endemic garlic varieties and found allicin contents ranging from 0.411% (Ufita flumeri var.) to 1.105% (Salomone var.). Similarly, another study reported that allicin content in raw garlic extracts can be as high as 0.46% (4.6 mg/g). Miron *et al*. (2004) revealed 37 mg/g allicin content in crushed raw garlic.

Allicin showed apoptotic and anti-Helicobacter properties; these compounds can have an important bioavailability in cancer prevention (Haghi *et al*., 2017); pretreatment with allicin could also attenuate stress, nicotinamide adenine dinucleotide phosphate (NADPH) oxidase activity, inflammation, mitochondrial respiratory chain dysfunction, and apoptosis in humans (Kong *et al*., 2017). Allicin has been used in six herbal formulas with different combinations of Astragalus polysaccharides (APS) and chlorogenic acid (CGA) on growth performance, non-specific immune response, antioxidant capacity, disease resistance, and damage to white shrimp biomolecules; levels of allicin used in diets were between 0.05% and 0.1% (Huang *et al*., 2018).

It is important to mention that concentrations of organsulphur compounds may increase when fresh garlic is subjected to soaking process with CaCl2. For example, Xu *et al*. (2015) established that The final 2-S-Allyl-L-cysteine (SAC) content reached 606.3 µg/g (i. e. 32 times higher than that in fresh garlic) after soaking for 72 h in a 10-mM CaCl2 solution at 10 °C, and the homogeneous reaction for 8 h at 37 °C. SAC was produced effectively through the homogeneous reaction with activated endogenous γ-GTP in garlic.

## 8. E- and z-ajoene content

Ajoene is represented by a wide range of organosulfur compounds related to garlic properties. Ajoene is chemically known as (E, Z)-4, 5, 9-trithiadodeca-1, 6, 11-triene 9-oxide, which is water stable (Martins *et al*., 2016). Ajoene is related

to the biological activities of garlic, created from allicin breakdown and non-enzymatic repair, and can also be obtained synthetically. It has been shown to induce apoptosis in cancer cells (Kaschula *et al*., 2016), as well as an antitumor effect in various types of cancer. Recent trials have shown that ajoene inhibits the proliferation of lung adenocarcinoma cells (Wang *et al*., 2016b). Garlic has also demonstrated beneficial effects for treating tinea capitis caused by *Microsporum canis*, a dermatophyte with known keratinophilic activity (Espinoza *et al*., 2015).

Ajoene can also act as an antifungal agent, which is safe and effective in treating chromoblastomycosis and some types of dermatophytosis. Its inhibiting concentrations can vary from 1.45 to 2.88 µM (Lemus-Espinoza *et al*., 2013). Ajoene content depends on garlic maturity. Vadekeetil *et al*. (2015), via high performance liquid chromatography (HPLC) analysis, showed approximate values of 221 mM ajoene per gram of garlic. Yoo *et al*. (2014) reported Z- and E-ajoene values between 0.12 and 0.22 mg/g and 0.12 and 0.11 mg/g, respectively, of macerated garlic oil.

Chen *et al*. (2018) recently identified 3-vinyl-1, 2-dithiacyclohex-5-ene (CAS: 62488-53-3), and 3-vinyl-1,2-dithiacyclohex-4-ene (CAS:62488-52-2) using GC-MS and established two major organosulfur compounds that represent 29.96% and 52.10% of the extract, respectively. Ajoene can usually be used as an antimicrobial component; for example, Choi *et al*. (2018) used ajoene in 3 mg/ml concentrations of extract to enhance macrophage antimycobacterial activity. Ajoene is also able to interfere with biological processes and is cytotoxic to cancer cells in the low micromolar range (6–8 µM) (Siyo *et al*., 2017).

## 9. Conclusions

Garlic (*Allium sativum* L.) is a vegetable with a great diversity of compounds, which create nutritional, functional, and pharmaceutical properties. These properties are closely associated with its content of sulfur compounds, such as allicin and ajoene, which various scientists have shown as beneficial to human health. The allicin and ajoene content of garlic varies with factors such as maturity, variety, and origin. Some health benefits of garlic are provided by its sulfur compounds, which can prevent hematological malignancies, cardiovascular disease, hypertension, mild hyperlipidemia, atherosclerosis, serum cholesterol, fibrinolytic, as well as some types of cancer. Future research should identify which garlic varieties contain the most allicin and ajoene based on current varieties and location in a specific region.

Studies about garlic have shown that certain components associated with its composition are beneficial for human health. However, garlic is still used as an alternative medicine. Alternative medical treatment methods are generally controversial because the promoted effects are not always the result of medical research based on rigorous long-term tests. New research must be conducted to solve this problem.

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