A Historical Review of Garlic as Medicinal Plant and Antioxidant in Modern Perspective

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Abstract

Over the ages, garlic has been regarded as a medicinal herb. Most historians date its origin to the Tienghan Mountain area of western China. According to the historical sources, the Sumerians were already using garlic to heal patients as early as 2100-2600 BC and probably contributed to its introduction into China, which later propagated to Korea and Japan. Garlic is commonly said to have been one of the earliest plants to be domesticated as a result of this profound antiqueness and early domestication. Modern research has elucidated the antioxidant ability of garlic since the 1980s. Its constituents neutralize reactive oxygen species and aid cellular glutathione in preventing lipid peroxidation and safeguarding major, such as proteins and DNA, against oxidative damage. Other data indicate cardiometabolic improvements, including the reduction of serum cholesterol and fibrinolytic activity. The historical applications of garlic and the current evidence of the antioxidant activities of garlic are united in this review. PubMed, Google Scholar, the Directory of Open Access Journals (DOAJ), PakMediNet, and the ScienceDirect sources were used to identify sources.

Keywords: Medicinal, Plant, Garlic, Antioxidant, Properties.

Introduction

Consumers around the world are shifting to natural antioxidants due to multiple health benefits (Khan et al., 2016). Spices are important ingredients of the human diet and mostly originate from plants (Sharma et al., 2025). The most common spices used in recipes are black and red pepper, ginger, turmeric, cumin, and garlic, etc. (Sharma et al., 2025; Sultan et al., 2014). Among all spices of the Alliaceae family, *Allium* is the most cultivated vegetable species (Mnayer et al., 2014; Petropoulos et al., 2020). Historical records show that garlic was widely used as a therapeutic agent by Egyptians, Greeks, Romans, and Chinese dating back over 5000 years. They used garlic for healing purposes, and to treat

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digestive infections and respiratory diseases (Biljana Bauer Petrovska, 2012). Hippocrates, father of Western medicine used garlic as a therapeutic remedy against different medical conditions even though scientists had not yet identified the chemical components inside garlic. Some important therapeutic properties of garlic are shown in Figure 1.

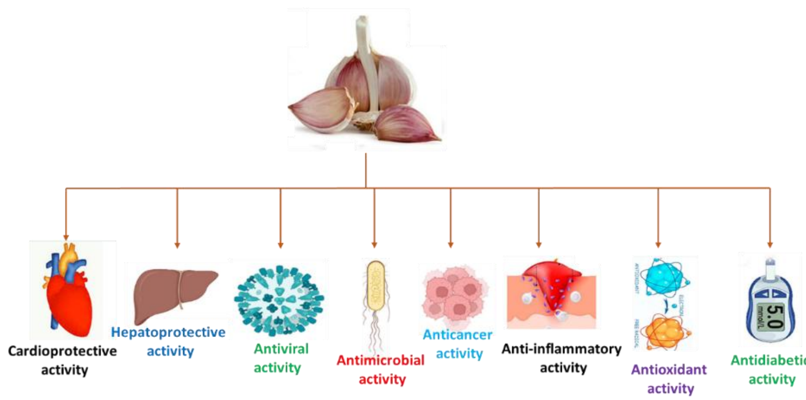

Figure 1: Some important therapeutic properties of garlic

Current research rediscovered the importance of garlic in new aspects such as antioxidant and antibacterial agents. Garlic is rich in vitamins, minerals, carotenoids, antioxidants, a variety of organosulfur compounds including allicin, diallyl disulphide, alliin, ajoene, and S-allyl cysteine and minerals like iron, germanium, selenium, calcium, and phosphorus (Gambelli et al., 2021; Gul et al., 2025). The presence of these minerals and organosulfur compounds enhances the therapeutic, antibacterial, and antioxidant ability of garlic (Gorrepati et al., 2024; Shakya & Das, 2025). Garlic compounds elevate the level of glutathione and different antioxidant enzymes in the cell that scavenge reactive oxygen species (ROS) and help cells combat oxidative stress. Because of this antioxidant property, garlic can be used in a variety of health disorders including pancreatic cancer (Kawasaki & Nussbaum, 2025) colon tumour (Jikihara et al., 2015), murine colitis (Fasolino et al., 2015; Zugaro et al., 2023), and non-alcoholic steatohepatitis (Barbhuiya et al., 2025; Wu et al., 2015). Different antioxidant compounds of garlic also reduce blood pressure (Prkasam et al., 2024), induce apoptosis in the gastric carcinoma cell line (Zhang et al., 2015), and act as an anticancer (Bhuker et al., 2024; Nicastro et al., 2015).

Historical Perspective of Garlic

Garlic has had a leading role in traditional medicine across cultures and times. Although others refer to it as being indigenous to the middle area (Jancic, 2002), some continue to identify its origin as the Tienghan Mountain region of western China. History records that as early as 2100 to 2600 BC, Sumerians were already using it therapeutically, and it is possible that they introduced it to China, where it was then extended to Korea and Japan (Cavagnaro & Galmarini, 2007; Tucakov & Todorović, 1984). Due to such antiquity, garlic is often depicted as one of the first plants that was grown by humanity. By approximately 2700 BC it was even prescribed to those who were depressed (Vanjkevic et al., 2002). The use of garlic is also mentioned as early as in the Avesta—the Zoroastrian collection of texts compiled in the 6th century BC—where it is referred to as a snakebite remedy, hypertensive, and infection. Table 1 gives a historical overview of what has been reported.

In South Asia, the Vedas mention garlic as a medicinal plant (Tucakov & Todorović, 1984). Hindu medicine employed the preparation of garlic as a tonic for poor appetite, cough, general debility, hemorrhoids, and skin conditions (Toplak-Galle, 2005). Ancient Egyptians used garlic as part of the daily pharmacopeia along the Nile and were reportedly using it to treat illnesses as well as strengthen slaves to do heavy labor, and because of their expertise in treating wounds, they caused neighboring cultures, such as the Israelites, Babylonians, Phoenicians, and Persians, who were used to semi-desert conditions and pastoral lifestyles, to adopt it for a wide range of uses (Tucakov and Todorovic, 1984; Vanjkevic et al., 2002).

Garlic was carried by ancient Israel communities to raise blood pressure, fight parasites, and stimulate appetite. The Talmud suggests consumption of garlic during the Friday meal, and the Bible makes a reference to a reaper's fare that involved cheese and garlic. In Greece, soldiers were fed garlic before going to war, and those that participated in the Olympics would use it to boost stamina and performance even when the temples had restrictions on the people who had eaten the meal (Gorunović et al., 2001; Vanjekvic et al., 2002). Greek doctors also reported medicinal applications: Hippocrates (460–370 BC) recommended garlic against intestinal parasites but also giardiasis, laxation, diuresis, and even dog and snake bites (Pelagic et al., 1970; Tucakov and Todorovic, 1984; Vanjkevic et al., 2002).

Parallel knowledge was kept in other traditions. Tibetan sources record cultivation and use in abdominal pain, alluding poetically to garlic as the rank rose, and Babylonian gardens are mentioned in this connection. It was also used practically in Roman times: Vergilius has written how to use crushed wild thyme and garlic against snakes; Columella (1st century) proposed to use it as an aphrodisiac, and Celsus (2nd century) had prescribed it against fever and tuberculosis (Tucakov, 1948). One of the early scholars of Galenic pharmacy, Galen (121–200 AD), employed the use of garlic in colic (Tucakov, 1948, 1996). Garlic was used as a remedy among Slavic peoples in relation to ulcerous crusts and snakebites (Nikolovski and Nikolovska, 1995).

In medieval times, garlic continued to feature in the medical books of Arab doctors (Tucakov, 1948). Taken together, these testimonies highlight the long-standing healing history of garlic throughout the geographies and centuries. In terms of religious perspective, it is mentioned in chapter 2, Surah Baqarah, of the Holy Quran (verse number 61), ‘‘And remember when ye said, O Moses! We can’t endure food of one kind. So, ask your lord to bring us what the earth grows, its pot herbs and cucumber, and lentils and garlic and onion.’’ Avicenna, in his book Al Qanoon Fil Tib, recommended the use of garlic in the treatment of arthritis, toothache, parasitic infection, constipation, chronic cough, and all other infectious diseases. Although it has medicinal and spiritual values, its pungent smell led to some restrictions in religious settings. The Prophet Muhammad (PBUH) advised against consuming garlic before attending congregational prayers. A well-known Hadith states: ‘Whoever has eaten garlic or onion should keep away from us or our mosque, and stay in his house (Khan, 1997). This emphasis on communal etiquette and cleanliness during worship.

This reflects the emphasis on communal etiquette and cleanliness during worship. Despite this, garlic is used in Islamic medicine widely as documented by Ibn Sina (Avicenna). He used garlic in his medicine to treat infections, digestive disorders and parasitic infections.

Garlic arrived in Great Britain in the year 1548, and it is possible that it came in via the trade routes in the Mediterranean (Vanjkevic et al., 2002). It was promoted as a treatment of skin disorders and helminth infections by the German botanist, Adamus Lonicerus (1528–1586) (Tucakov, 1996). In 1720, in Marseille, the plague; modern records attributed the saving of thousands of people to the use of garlic (Vanjkevic et al., 2002). Louis Pasteur outlined its antibacterial activity in 1858, and subsequent reports claimed activity even against Helicobacter spp. The earliest known records of antiseptic action were shown in 1918 in Beirut against the pathogens of typhoid, diphtheria, and cholera (Tucakov, 1948). The same year, a French physiotherapist, Lekrek, suggested using garlic as a treatment for pandemic influenza, and people are reported to have been wearing necklaces of garlic as a generic preventive measure (Tucakov, 1948, 1996).

In Russia, the use of garlic was still widespread: doctors used it with penicillin to treat the respiratory infections in children, and it was used in different military environments by the Red Army, which made it known as an apparently natural or Russian antibiotic (Tucakov, 1996). Indian and Chinese historical texts also report usage against parasitic infections and in the treatment and care of leprosy (Rivlrn, 1998).

Table 1: Some historical medical and ethnobotanical uses of garlic.

Uses/Remedy	Nation/Scientist	Era/ Year	Reference
Depression		2700 BC	(Vanjkevic et al., 2002)
Snake bites, hypertension and infection	Avesta	6th-century BC	(collection of Zorastrain)
Loss of appetite, cough, common weakness, haemorrhoids and skin diseases	Ancient Indian		(Toplak-Galle, 2005).
Treatment of diseases in slaves	Egyptians		(Tucakov & Todorović, 1984)
to increase blood pressure, eliminate parasites, and stimulate appetite.	Ancient Isralian		(Vanjkevic et al., 2002).
Utilized in the Olympics for increasing stamina and better performance	Greek athletes		(Gorunović & Lukić, 2001; Vanjkevic et al., 2002).
Against intestinal parasites and as laxative against diuretic conditions.	Hippocrates	(460-370 BC)	
In regulation of the menstrual cycle, in seasickness and colic relief	Discorides	(40-90 AD)	(Pelagic et al., 1970; Vanjkevic et al., 2002),
Against dog and snake s' bite	Discorides	(40-90 AD)	(Tucakov & Todorović, 1984).
Stomach-aches	Old Tibetans		
As aphrodisiac	Columel	1st century	(Tucakov, 1948)
Fever and tuberculosis	Celsius	2nd century	(Tucakov, 1948)
Against colic and regulation of digestion	Galen	(121-200 AD)	(Tucakov, 1948, 1996)
Ulcer crust, spider, snake bites and lice	Slavic people		(Nikolovski & Nikolovska, 1995)
Toothache, constipation, arthritis, parasitic infection, cough and infectious diseases	Avicenna		

Historic Names of Garlic

Garlic has different names which not only depict its medical and symbolic significance but also show a close relation with cultural and spiritual life (Yaniv Bachrach, 2025). For example, Ancient Egyptians called the garlic the "Plant of immortality" which Highlights its role in the mummification, rituals and food of workers (Metwaly et al., 2021). Ancient Greece used garlic in treating snakebites and thus called Snake grass (B. B. Petrovska, 2012). In Roman culture it is called a stinking rose due to its pungent smell and medical properties (Yaniv Bachrach, 2025). In Chinese traditional medicine, garlic is called the divine herb due to its value in treating diseases (Ye et al., 2022). Garlic is known as the 'bride's food' due to its role in marital customs and aphrodisiac properties. (Dhall et al., 2023). Africans recognized the spiritual healing of garlic in warding off evil spirits and called as the protector (Abera & Mehari, 2018).

The ethnobotanical importance of garlic spread across ancient cultures because different groups developed nearly identical applications for the plant despite lacking any contact with one another. The ancient Egyptians employed garlic as their main source of nourishment while simultaneously utilizing it in their religious offerings because garlic expressed their need for strength vitality and protection (Metwaly et al., 2021) . The traditional medical literature of India first incorporated garlic as a Rasayana around 2000 BCE to boost immunity and support digestion (Bayan et al., 2014). Traditional Chinese medicine utilized dynamic antibiotic properties of garlic to treat gastrointestinal and respiratory conditions thus garnering the status of "the divine herb" (Tan et al., 2017). Garlic became part of traditional healing practices across Sub-Saharan Africa after the first century CE and was applied for treating common respiratory infections alongside other medical needs (Abera & Mehari, 2018).

During the Columbian Exchange in the 16th century, garlic migrated to the Americas where the Cherokee Indigenous population used it to treat wounds and digestive problems as well as antiseptic applications (Moerman, 2009). People across various parts of the world utilize garlic through their traditional as well as nonformal medical systems today. Ethiopia continues to use garlic as a primary remedy for livestock respiratory illnesses according to Kokwaro (2009). The city of Lagos in Nigeria recognizes garlic as a common and accessible medication used by residents to treat their daily medical issues which shows its enduring position in personal healthcare practices (Akerele et al., 2016). This persistent use underscores garlic's cultural adaptability and the enduring trust in its medicinal value.

Modern interdisciplinary inquiries confirm the traditional medicinal practices related to garlic. Genetic research has documented the historical selection of garlic strains through breeding programs to sharpen its therapeutic capabilities while showing how human societies developed its medical advantages across different generations. Scientists use computational models particularly machine learning tools to prove the scientific benefits of traditional garlic preparations including antimicrobial and antioxidant effects together with cardioprotective properties (Verma et al., 2023). The contemporary validation techniques demonstrate how traditional knowledge about garlic continues to contribute intellectually to modern medical and pharmaceutical investigations.

Garlic as an Antioxidant

The antioxidant property of garlic was established by the early 1980s. Follow-ups demonstrated that its ingredients quench reactive oxygen species (ROS) and increase cellular glutathione, thereby reducing lipid peroxidation and preserving major biomolecules, including proteins and DNA, against oxidative damage (Doreswamy et al., 2004). In addition to redox effects, the intake of garlic has been linked with reduced serum cholesterol and alteration of fibrinolytic pathways. Dietary supplementation of fish with garlic has been associated with decreased mortality, improved antioxidant status, and increased growth performance in fish (Hirata et al., 2025; Metwally, 2009).To a great extent, these benefits can be explained by the organosulfur compounds like allicin, diallyl disulfide, and S-allyl-cysteine, which neutralize ROS and reduce oxidative stress, which is one of the factors driving the chronic disease processes (cardiovascular and neurodegenerative diseases, metabolic diseases like diabetes, and cancer) (Borlinghaus et al., 2014).

Research shows that vital antioxidant compounds, including S-allyl cysteine, form during the ageing process of aged garlic extract (AGE), making this preparation particularly effective for antioxidant function (Rivlin, 2001). Studies demonstrate that garlic-derived compounds improve endogenous antioxidant enzymes including superoxide dismutase (SOD), catalase as well as glutathione peroxidase to enhance the protection of intrinsic defense systems (B. Wang et al., 2025). The high content of Amadori compounds and polyphenols in black garlic which comes from fermented garlic drives its ability to eliminate free radicals (Kim et al., 2012; Verma et al., 2023). Multiple laboratory research demonstrates that garlic supplementation helps minimize biomarkers of cell damage and enhances protective actions against toxins for healthy people alongside patients with ongoing medical conditions (Askari et al., 2021). As a natural antioxidant garlic functions to provide dietary supplementation yet shows potential value as an addition in relieving oxidative stress (Sheir et al., 2025).

Reader's guide to how garlic fights oxidative stress. Reactive oxygen species (ROS) are reactive forms of oxygen that can damage fats, proteins, and DNA. Superoxide dismutase (SOD) converts the superoxide radical to hydrogen peroxide. Catalase (CAT) and glutathione peroxidase (GPx) then turn hydrogen peroxide into water. Glutathione (GSH) is a small antioxidant GPx uses to neutralize peroxides, and glutathione S-transferase (GST) attaches GSH to toxic by-products so cells can remove them.

Where garlic fits: sulfur compounds such as allicin, S-allyl cysteine (SAC), and diallyl sulfides (DADS/DATS) can ① neutralize some ROS, ② maintain cellular GSH so GPx/GST keep working, ③ increase the activity/expression of SOD, CAT, and GPx, ④ chelate transition metals to limit Fenton chemistry. Together, these actions reduce lipid peroxidation and help protect proteins and DNA (Amagase et al., 2001; Colín-González et al., 2012; Rahman, 2007; Borlinghaus et al., 2014).

Prep note: fresh-crushed garlic is rich in short-lived allicin, whereas aged/processed forms provide more stable SAC; preparation, dose, and duration partly explain variable effect sizes across studies (Amagase et al., 2001; Borlinghaus et al., 2014).

Mechanism of Garlic Antioxidant Behaviors

Organosulfur compounds are a major cause of the antioxidant ability of Allium spp. (Gul et al., 2025; Nishimura et al., 2006; Singh and Singh, 2008). Allicin, alliin, and diallyl sulfide are the most prominent contributors (Hirata et al., 2025), and trace minerals, dietary fiber, and polyphenols contribute to the overall activity as well (Vuković et al., 2023). Fructo-oligosaccharide fructans produced by aged garlic have the ability to stimulate macrophage phagocytosis (Chandrashekar & Venkatesh, 2012).These biochemical effects are evidenced in vivo: when Allium homogenates were administered to male albino Wistar rats in a short-term period, both enzymatic (SOD, CAT, GR, GPx) and non-enzymatic (ascorbic acid, GSH) antioxidant defenses of liver tissue were significantly increased, signifying protection against the ethanol-induced injury (Nencini et al., 2010). The reproducible evidence demonstrates that the daily intake of garlic improves endogenous antioxidant enzymes (Ali et al., 2023; Amagase et al., 2001), inhibits lipid peroxidation by enhancing intracellular GSH, disrupts the propagation of peroxyl-radical chains in membranes (Colín-González et al., 2012b), and binds transition metals to restrain iron- and copper-mediated Fenton chemistry and the ensuing. The Nrf2 pathway activation and inhibitory action on NF-κB by garlic results in a reduced inflammatory stress burden through increased antioxidant response element (ARE)-driven gene expression (Chan et al., 2013). The protective nature of garlic results from its combined mechanisms which shield cells from oxidative damage and related diseases. The active compounds in garlic mimic the activity of the following antioxidant enzymes;

SOD (Super Oxide Dismutase) Activity

SOD deals with oxyradicals and catalase the conversion of superoxide into H_2O_2 and O_2. Garlic exhibits SOD-like activity directly or indirectly through bioactive compounds. SOD was isolated and purified from garlic by Liu et al. (2011). Hadji et al. (2007) further isolated SOD1 (Mn-superoxide dismutase) and Cu, Zn superoxide dismutase; referred to as SOD2 and SOD3. Sephacryl S200-HR gel filtration was used for the purification of SOD2. SOD2 exhibits a wide tolerance range with pH ranging from 5.0 to 10.0 and temperatures from 25 to 60^{o} C. Zhang et al. (2003) also isolated and purified the SOD from garlic petals soaked in $CaCl_2$ and purified in acetone precipitation in grades. The presence of SOD confirmed that the use of garlic can mimic SOD activity in oxidative stress. In another study by Nasr (2014) aged garlic extract restored the activity of SOD in cisplatin-treated rats. Wang and Sun (2017) believed that the SOD activity of the natural antioxidant system is enhanced because of the presence of polyphenols in garlic. Further, Research shows that SAC derived from garlic enhances both SOD expression and SOD enzyme activity in tissues (Colín-González et al., 2012b). It actively scavenges superoxide radicals in in-vitro systems in addition to inducing SOD enzyme activity (Banerjee et al., 2003; Lee et al., 2009; Y. Wang et al., 2025). The SOD-mediated detoxification pathway receives reinforcement from garlic supplementation making it an important dietary antioxidant.

GST (Glutathione S-transferase) Activity

The phase II detoxifying enzymes GSTs (Glutathione S-transferases) facilitate the GSH (glutathione) based conjugation of diverse electrophilic compounds. The biochemical process provides fundamental protection to cells against oxidative stress while facilitating detoxification processes involving xenobiotics carcinogens and products from oxidative damage (Hayes et al., 2005; Li, 2025). GST activity is modulated in garlic by some of its organosulfur compounds, including diallyl sulfide (DAS), diallyl trisulfide (DATS), and diallyl disulfide (DADS) (Tsai et al., 2005). GST, in the lung and liver of treated rats, is also mimicked by allyl methyl trisulfide. GST activity is also enhanced by allyl derivatives (Sparnins et al., 1986). Further, a study by Kim et al. (1994) showed garlic treatment enhanced the GST activity in rat liver. These organosulfur compounds actively detoxify the carcinogens. Several laboratory research on living and non-living biological samples prove that these compounds from garlic either improve body GST capability or show GST-like detoxification functions that mimic GST reactions (Gorrepati et al., 2024; Pérez-Torres et al., 2022). Studies further documented that garlic demonstrates GST-like behavior in particular in vitro systems. The electrophilic structures of organosulfur compounds in garlic allow them to conduct glutathione conjugation with reactive intermediates similar to GST activity. The organosulfur compounds present in garlic support detoxification pathways although they lack enzymatic structure but activate or reproduce GST pathway's behavior (Amagase et al., 2001).

GSH (Glutathione) Activity

The intracellular tripeptide glutathione (GSH) comprises three amino acids; glutamine and cysteine joined with glycine (Jefferies et al., 2003). GSH functions either directly by combating ROS or by providing material support for enzyme activities of glutathione peroxidase and glutathione S-transferase (Csiszár et al., 2016; Liu et al., 2022). The important role of GSH maintain redox equilibrium while working to detoxify xenobiotics compounds and facilitate immune response. Recent scientific reports show that garlic possesses known therapeutic properties which influence GSH levels throughout both laboratory and animal testing environments (Askari et al., 2021). Organosulfur compounds from garlic like S-allyl cysteine (SAC), diallyl disulfide (DADS), and diallyl trisulfide (DATS) help strengthen antioxidant mechanisms that produce and renew GSH. Garlic also retains selenium; an important cofactor of GSH activity (Leong et al., 2010). Further, this herb species contains a variety of organosulfur compounds including allicin and diallyl sulfide. These are the precursors for glutathione synthesis (Wei & Lau, 1998).

A study by Savira et al. (2023) investigated the effects of garlic ethanol extract on GSH levels in a rat model exposed to cigarette smoke. The results demonstrated that the group receiving garlic extract had significantly higher GSH levels compared to both the control and smoker-only groups, suggesting garlic extract supports GSH maintenance during smoking exposure. Another review by Berkheiser (2023) highlights that sulfur-rich foods, such as *Allium* can boost GSH levels enhancing the body's antioxidant capacity. Another study conducted by Manoj Kumar et al. (2017) established that garlic extract protected the liver, brain and kidney tissues of lead-exposed rats from oxidative stress through its ability to restore glutathione. The research demonstrated that garlic affects GSH restoration and lowers lipid peroxidation.

Role of Active Compounds in Antioxidative Activity

Garlic contains a large amount of sulfur-containing antioxidant compounds. These compounds can broadly be classified into two categories i.e. cysteine sulfoxides and γ-glutamylcysteine. γ-glutamylcysteine transforms into alliin which ultimately yields allicin; an important antioxidant of garlic (Farooqui & Farooqui, 2017). Alliin readily converts into allicin in the presence of an alliinase enzyme. This phenomenon is stimulated by crushing the fresh garlic cloves (Ariga & Seki, 2006; Gu & Zhu, 2011). Allicin, on heating, further transforms into its metabolites including ajoene and diallyl sulfide (Farooqui & Farooqui, 2017) (Fig.1). Some important antioxidant compounds of garlic, including ajoene, alliin, allicin, and S-allyl cysteine, are listed in Table 2.

Table 2: Isolated compounds with antioxidant activity from garlic.

Compound Name	Molecular Formula	Origin/ Sp.	Solvent	Reference
Allicin	$C_6H_{10}OS_2$	Korean	Water	(Yoo et al., 2010)
		Australian	Water	(Sterling & Eagling, 1997)
		USA	Water	(Koch & Lawson, 1996)
Alliin	$C_6H_{11}NO_3S$	Korean	Water	(Yoo et al., 2010)
		Germany	Water	(Bloem et al., 2011)
		Japanese	Water	(Shimpo et al., 2002)
Ajoene	$C_9H_{14}OS_3$	Japanese	Soybean oil	(Apitz-Càstro et al., 1983)
			Rice Oil	(Naznin et al., 2008)
Diallyl sulfide	$C_6H_{10}S_2$	Greek garlic	Diethyl ether	(Kimbaris et al., 2006)
		Korean garlic	Dichloromethane	(Lee et al., 2003)
S-allyl cysteine	$C_6H_{11}NO_2S$	Korean	Water	(Yoo et al., 2010)
		USA	Water	(Amagase & Milner, 1993)

Allicin

Allicin actively scavenges the OH- radicals (Long et al., 2025; Tiwari et al., 2018). Pharmacokinetic studies of allicin suggest a hydrophobic nature which can cross the cell membrane, without damaging its phospholipid bilayer structure, and metabolized rapidly (Chan et al., 2013). Each clove of fresh garlic contains 5 to 6mg of allicin (Horev-Azaria et al., 2009). Absorption of allicin is followed by its catabolism into different metabolites including allyl methyl sulfide and acetone.

Allicin plays a significant role in coping against cytotoxic substances and scavenging (Hirata et al., 2025). It is done by generating different antioxidant products. This highlights the importance of allicin in cell protection against oxidative stress by actively reducing ROS concentration (Zhuang et al., 2023). It has been proved in a study on aortic-banded mice, with cardiac hypertrophy, where allicin lowered the ROS level by 50 per cent (Liu et al., 2012). Allicin, by halting the formation of conjugated diene hydroperoxides (ROS-derived molecule), suppresses lipid peroxidation (Okada et al., 2005). Allicin can also elevate the glutathione content of the cell which ultimately helps cells in combating oxidative stress (Horev-Azaria et al., 2009; Lam et al., 2023). detoxifying enzymes). Allicin further suppresses lipid oxidation; indicating its antioxidant ability (Okada et al., 2005). Invitro studies on allicin treatment of human umbilical vein endothelial cells suggest the presence of different allicin derivatives including S-allylmercaptocysteine and S-allylmercaptoglutathione (Horev-Azaria et al., 2009). Both these allicin derivatives are capable of increasing the glutathione content of the cell. Allicin actively reduces the risk of oxidative stress-induced cell injury by up-regulation of genes of various antioxidant or detoxifying enzymes (i.e.

cytoprotective enzyme and phase II. The interaction of various biological components within the cell also regulates the antioxidant properties of allicin. For instance, allicin exchanges the thiol group with xanthine oxide; inhibiting its ability to superoxide formation (Chung, 2006; Rabinkov et al., 1998).

Alliin

Alliin (also referred to as S-allyl cysteine sulfoxide) an amino acid (cysteine) derivative is a natural component of garlic (see Figure 2). Alliin was first discovered in 1947 by Stoll and Seebeck (1947). Alliin readily converts into allicin in the presence of an alliinase enzyme. This phenomenon is stimulated by crushing the fresh garlic cloves. In the case of intact garlic, alliin exists in its reduced form. It is an important organosulfur compound of AGE (aged garlic extract) (Ariga & Seki, 2006; Gu & Zhu, 2011). It is usually absorbed into the blood via the intestine; exhibiting a hypoglycemic effect. It also elevates the blood insulin level (Augusti & Sheela, 1996). Alliin can modulate enzymatic systems including SOD, CAT and GPx and reduce oxidative stress. It possesses hydroxyl radical-scavenging potential (Kourounakis & Rekka, 1991). Alliin also scavenged superoxide (Chung, 2006). Further, Kourounakis and Rekka (1991) suggested that alliin indirectly regulates the scavenging of hydroxyl radicals by transforming into allicin. A study by Bayan et al. (2014) can inhibit lipid peroxidation and protect against oxidative damage in chronic diseases.

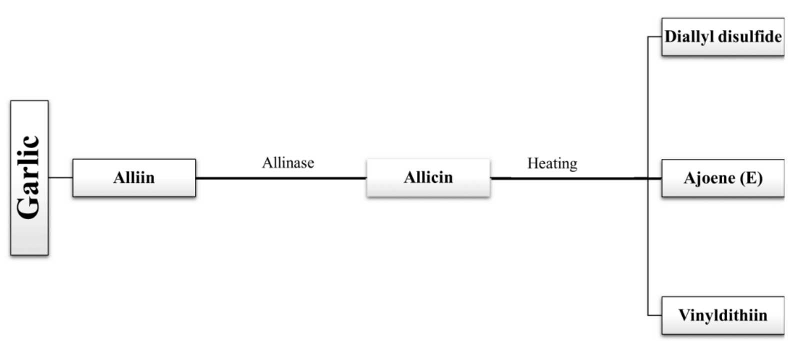

Figure 2: Alliin and its metabolites (important antioxidant compounds of garlic).

Ajoene

Ajoene is colorless and organosulfur compound derived from the rearrangement of allicin. It is widely studied for its antioxidant and cytoprotective properties. Ajoene is more chemically stable compared to alliin and allicin. It is predominantly formed in oil or alcoholic garlic preparations. It contains both disulfide and sulfoxide functional groups and is colorless in nature. Ajoene got its name from Spanish ''Ajo'' means garlic (Block et al., 1984). Two isomeric forms of ajoene exist in nature; cis (Z) ajoene and trans (E) ajoene; possessing different bioactivity (Erkoç et al., 2003). Z-isomer of ajoene is considered more potent than E-isomer (Block et al., 1984). Therefore, the antioxidant activity of Z-ajoene is relatively greater than E-ajoene. Maeda and Morita (2010) in their research inferred that Z- Z-Ajoene is more effective than E-ajoene. Ajoene also acts as an antioxidant due to its ability to suppress the release of superoxide. This activity of ajoene is primarily due to hydrogen atoms bonded with the central carbon atom. These hydrogen atoms, in a proton transfer reaction, readily leave the molecule because of their high electro-positivity among other hydrogen atoms of the ajoene (Erkoç et al., 2003). Additionally, ajoene has been shown to modulate redox-sensitive signaling pathways, including the nuclear factor erythroid 2-related factor 2 (Nrf2) pathway, which plays a critical role in cellular defense against oxidative stress. These properties suggest that ajoene contributes significantly to garlic's protective role against oxidative damage associated with chronic diseases (Elosta et al., 2017).

Diallyl Disulfide (DADS)

Diallyl sulfide (DAS), diallyl trisulfide (DATS), and diallyl disulfide (DADS) are among the most important oil-soluble organosulfur compounds of garlic. Out of these most important is diallyl disulfide (DADS); because of its role in various biological processes (Robert et al., 2001; Thomas et al., 2002). This biological process includes prevention against genotoxicity, neurotoxicity, and cancer (Fukao et al., 2004; Guyonnet et al., 2002; Kim et al., 2016; Manesh & Kuttan, 2002; Nakagawa et al., 2001; Pedraza-Chaverrí et al., 2003). It has been experimentally proved that garlic powder, containing different organosulfides i.e. DAS or DADS, play a significant role in suppressing the chemically induced carcinogenesis in the lungs, liver, oesophagus, colon, and mammary glands (Huard et al., 2004). Reduced level of N-nitrosopiperidine mutagenicity and DNA breaks in the liver (by aflatoxin B1 and N-nitrosodimethylamine) is also characterized by the presence of DADS (Guyonnet et al., 2001). Diallyl disulfide induces apoptosis for tumor cells degradation; in the human colon (Sundaram & Milner, 1996). DADS also plays an important role in the activation of various phase II enzymes (Munday & Munday, 1999).

S-Allyl Cysteine (SAC)

S-allyl cysteine is an important compound of AGE (aged garlic extract). It is a white crystalline powder with a 223.3 C to 223.7oC melting point and a characteristic odour (Kodera et al., 2002). Enzymatic catabolism of γ-glutamyl-S-acetylcysteine in the presence of γ-glutamyltransferase yields S-allyl cysteine (Extract, 2006). It is a stable compound and can be sustained in aged garlic extract for more than two years (Lawson, 1998). It is 30 times less toxic than other antioxidant compounds of garlic i.e. diallyl sulfide and allicin (Amagase et al., 2001). SAC is easily detectable after oral consumption of garlic and is extensively used in different studies, related to garlic consumption, as human compliance marker (Steiner & Li, 2001).

SAC is an important antioxidant of garlic. Antioxidative properties of SAC are mainly because of the presence of the thiol group which acts as a nucleophile and neutralizes the electrophilic free radicals; making them less reactive (Colín-González et al., 2012a). SAC plays an important role in elevating the concentration of different antioxidant enzymes in plasma and reducing the level of reactive oxygen species (ROS) (Dvořáková et al., 2016; Hsu et al., 2004). Ide et al. reported the scavenging effect of SAC on hydrogen peroxide. SAC also inhibits the hydrophilic radical initiators from starting the chain oxidation reaction (Ide et al., 1996). It also resists the oxidation process of lipoprotein (LDL), thus playing an important role in lowering the cell injury caused by oxidized low-density LDL (Ide & Lau, 1999). While studying gentamicin-induced acute renal failure, Maldonado et al. (2003) analyzed the role of SAC in lowering oxidative stress and regulating antioxidant enzyme activity.

Discussion

The comprehensive and expansive historical record, with current scientific evidence, supports the proposition that A. sativum is a powerful medicinal plant with antioxidant properties. This review will integrate historical uses with contemporary research, explaining the mechanistic reasons for the efficacy of garlic. it will also review historical medicinal uses in the context of contemporary findings, along with challenges, future considerations and opportunities for advancement and utilization of garlic.

Garlic has a long and extensive history, from its use by the Sumerians (2600-2100 BC), as well as in World Wars I and II, not merely anecdotal, but now underpinned by a clear biochemical rationale (Cavagnaro & Galmarini, 2007; Tucakov, 1996). Previous uses of garlic for treating infections, wounds, respiratory illnesses, and fatigue find modern validation in garlic's wide array of antimicrobial, immunomodulatory, and antioxidant activities (Bayan et al., 2014; Gorrepati et al., 2024). For example, the use of garlic to "fortify slaves," or to increase the physical capacity of Greek athletes (Gorunović & Lukić, 2001), corresponds to our modern understanding of the involvement of oxidative stress as a large contributing factor related to physical fatigue or damage to human tissue. The modern identification of organosulfur compounds (OSCs) active in garlic, such as allicin, S-allyl cysteine (SAC), and diallyl disulfide, provides the biochemical basis for the ancient assertions of garlic usage (Borlinghaus et al., 2014).

Compounds with antioxidant properties, such as allicin and SAC, directly scavenge reactive oxygen species (ROS), thereby preventing lipid peroxidation (Chung, 2006; Ide et al., 1996). Another mechanism of antioxidant activity is the enhancement of the body's endogenous antioxidant enzymes. When supplementing the diet with garlic, it has been shown consistently to increase the activity and expression of important antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) (Amagase et al., 2001; Nencini et al., 2010). Further, it also maintains and enhances cellular levels of glutathione (GSH) (Horev-Azaria et al., 2009; Savira et al., 2023). GSH is the cell's major redox buffer and a cofactor for GPx and GST. Its maintenance is an important component of both anti-apoptosis and detoxification. Research in the last decade has expanded our knowledge from scavenging ROS to recouperating from cellular damage partially through gene regulation. Several reports have demonstrated activation of the Nrf2 pathway by garlic OSCs. On a mechanistic level, Nrf2 is the master regulator of the antioxidant response element (ARE). Activation of the Nrf2 pathway results in the coordinated expression of a plethora of cytoprotective enzymes (Chan et al., 2013; Colín-González et al., 2012b).

Despite the fact that the evidence is convincing, it is necessary to acknowledge several limitations. Much of the substantial mechanistic data originates from either in vitro or animal studies. Clinical trials in humans are often limited by small sample sizes, short durations, and generally do not standardize the garlic preparations (Askari et al., 2021). Future research must focus on: Large-scale, long-term, randomized controlled trials using high-quality garlic formulations (with specific amounts of key OSCs like allicin or SAC) are needed. When garlic is used for a specific health condition, it is important to establish the optimal dose before we can begin making recommendations based on tradition or evidence. Omics technologies (e.g., transcriptomics and proteomics) could provide an overview of the effects of garlic on antioxidant and inflammatory pathways, and give us new biomarkers and mechanisms. While garlic is generally considered safe for most people, especially in the amounts a typical person would consume, we must remain aware of the potential for Garlic (especially in high doses or certain preparations) to cause interaction with or affect the safety and effectiveness of anticoagulants and certain other medications, and educate patients of these considerations.

Conclusion

Garlic is a medicinal crop that has passed through millennia, and the modern evidence supports the explanation. In cell, animal, and limited clinical experiments, organosulfur compounds, in particular allicin, S-allyl-cysteine, and diallyl sulfides, are repeatedly found to promote endogenous antioxidant systems. Garlic inhibits lipid peroxidation by neutralizing reactive oxygen species, maintaining glutathione levels, increasing the enzyme relay between SOD and CAT/GPx, and preserving proteins and DNA. Such redox effects correspond with broader indicators in cardiometabolic and inflammatory contexts. Aquaculture data also demonstrate analogous processes in non-human systems. Meanwhile, the current literature is heterogeneous. The effect depends on the preparation (fresh-crushed or aged/standardized extracts), dose, stability of formulations, time of administration with respect to food, and duration of intervention. Quantitative allicin activity is transient and greatly preparation-varying, but S-allyl-cysteine is more persistent but not exactly identical in activity. Small sample sizes, divergent endpoints, or even non-reporting are frequently used in many studies, restricting direct synthesis and clinical generalization. Rigor and comparability should be emphasized in future work: head-to-head and dose-standardized randomized trials across different major preparations; harmonized biomarker panels (e.g., SOD, CAT, GPx, GSH, MDA, 8-oxo-dG) and clinical endpoints (blood pressure, lipids, liver fat, functional status); pharmacokinetics and bioavailability should be characterized by matrix and food co-ingestion; and readouts of mechanistic processes (transcriptomic/proteomic signatures of antiox The prespecifications should include targeted populations (hypertension patients, dyslipidemia, non-alcoholic fatty liver disease, high oxidative-stress burden, etc.) and follow drug-herb interactions (particularly with anticoagulants/antiplatelets and antihypertensives) and safety/tolerability. As practice, garlic is to be regarded as an adjunct, not a substitute, to routine care. Preparation is important: the type of product, quantified actives (where present), dose, and duration should be reported so that clinicians and researchers can replicate and make informed decisions. Assigning evidence-based, standardized preparations; matching dosages with available evidence on similar preparations; and providing advice on typical, generally benign adverse events (e.g., gastrointestinal upset, odor) and on potential interaction risks is all practical advice. These steps will allow us to translate the long history of the use of garlic with a view to less ambiguous, clinically significant applications based on the modern methodology.

Declaration of interests

The authors confirm no conflicts of interest.

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