Phytochemical Screening of Garlic (*Allium sativum*) and Its Antioxidant and Antimicrobial Activities

Arfa[1], Tehreem[1], Gulzar Akhtar[1], Rahid Ali[2], Rukhsana Yousaf[1], Sarib Shahid[3], Momina Iftikhar[3], Irum Shehzadi[4], Syed Faizan e Mustafa Gillani[5] and Usama Zafar Iqbal[1,*]

[1]Department of Botany, University of Agriculture, Faisalabad, Pakistan
[2]Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan
[3]Department of Bioinformatics and Biotechnology, Government College University, Faisalabad, Pakistan
[4]Soil and Environmental Sciences Division, Nuclear Institute for Agriculture and Biology, Faisalabad, Pakistan
[5]Department of Entomology, University of Agriculture, Faisalabad, Pakistan
*Corresponding author: usamaniazi1010@gmail.com

Abstract

This study investigates the phytochemical composition of garlic (Allium sativum) and determines its antioxidant and antimicrobial activities. By employing routine extraction methods, major phytochemicals like flavonoids, phenols, and sulfur compounds were isolated. Antioxidant activity was determined by 2, 2-diphenyl-1-picrylhydrazyl (DPPH) and 2, 2-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assays, both of which showed significant free radical scavenging activity. Antimicrobial activity was tested against different bacterial and fungal pathogens with agar diffusion and minimum inhibitory concentration (MIC) assays. Data from several studies indicated that garlic has powerful antimicrobial activity, especially against gram-positive bacteria, and significant antioxidant activity, as elaborated in this chapter. These findings support the long-standing medicinal application of garlic and identify its value as a natural antioxidant and antimicrobial compound for food preservation and therapeutic purposes. The isolation of active constituents and elucidation of their mode of action require ongoing research.

Keywords: Antioxidant, Anti-microbial, Phytochemicals, Garlic, Antifungal

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Introduction

In the world of natural medicine, garlic is among the strongest healing herbs. Allium sativum is a member of the Alliaceae group, science says. Garlic is commonly known for its uses in food, but its health-promoting advantages far outweigh its flavor. The pungent antibacterial and antioxidant effects of this unassuming plant are due to all-natural chemicals known as phytochemicals (Lissiman et al., 2014). Numerous tasty wild and farmed *Allium* species may thrive in the moderate tropical climate of the Northeast (Iskandar & Mustarichie, 2019). Garlic has been extensively utilized as a healthy food ingredient and a valuable source of natural substances supporting human health in diverse cultures. Garlic is also a great source of antioxidants, flavonoids, and essential vitamins (particularly B-complex and C) and minerals (especially phosphorus, potassium, and selenium). It also contains other non-volatile trace elements that are characterized by significant curative and medicinal properties. Some examples of these are proteins, amides, phenolic compounds, nitrogen derivatives, flavonoids, and saponins (Lawson, 1993).

Medicinal herbs are useful in the treatment of human diseases because of the presence of bioactive compounds. Alkaloids are strong biologically active compounds that can be used for healing in segments of medicinal plants (Ameh et al., 2013) The aroma of minced garlic and the breath resulting from consuming it has been a distinguishing characteristic. Allicin is the primary source of fresh cut garlic's odor, while diallyl disulfide dominates after 30 minutes, with diallyl and allyl methyl trisulfides and small quantities of their disulfides being primarily responsible for cooked garlic's aroma (Baron et al., 2011). The main reason for the first breath smell after consuming fresh garlic is allyl mercaptan; however, this is throat smell and passes after an hour or so (Williams et al., 2001). The smell discharged from the lungs gets stronger progressively and persists for more than twenty-four hours. This is as a result of thiosulfate's decomposition and consists predominantly of allyl methyl sulfide (87% of sulfur compounds after nine hours) and dimethyl sulfide (11%). Despite the presence of garlic's smell in human breast milk, babies appear to love its taste, as they will nurse for a longer time when their mothers have taken garlic (Mennella & Beauchamp, 1991).

Garlic: A Powerful Medicinal Herb

Garlic has been used in many civilizations because of its ability to treat infections, boost the immune system and support heart health from ancient Egyptian physicians to modern research. A nutrient-dense superfood, garlic has many health benefits since it is rich in vitamins, minerals, and bioactive compounds (Mirelman et al., 1975). Garlic is a nutritional powerhouse with numerous health benefits due to its abundance of vitamins, minerals, and bioactive chemicals (Bradley et al., 1992). Ancient Chinese and Japanese cultures employed it to relieve sore throats, fevers, ailments, and headaches. Greek medical practitioners such as Hippocrates and Galen administered it for the treatment of digestive and non-digestive disorders. In Nigeria, especially in Africa, it is used to treat respiratory infections, diarrhea, abdominal discomfort, and middle ear infections (otitis media) (Souiden & Jabeur, 2015). It was also used to treat asthma, allergic rhinitis (hay fever), and the common cold in Europe and India. Due to its broad use both as a topically and internally applied antimicrobial agent, garlic has been given the nickname "Russian penicillin." It is also frequently used throughout many cultures as a medicinal agent because of its well-established healing effects (Timbo et al., 2006).

Garlic has been utilized as a remedy to manage numerous cardiovascular and circulatory system disorders and conditions, including hypertension, elevated cholesterol levels, coronary artery disease, heart attacks, and arterial stiffening (atherosclerosis), primarily due to its biologically active compound allicin and its derivatives (Mirelman et al., 1975).

Garlic has been identified to be a very effective treatment against the herpes simplex virus and the influenza B virus, according to numerous scientific studies. The latest double-blind, placebo-controlled trial to demonstrate enhanced protection against the common cold virus was carried out. The Garlic Centre undertook the first significant study to demonstrate the benefits of taking Allimax Powder capsules once a day for prevention, treatment, and reinfection reduction, and it was published in Advances in Therapy (Josling, 2001). Garlic has a variety of actions. In vitro studies have confirmed that garlic has antibacterial, antimycotic, and antibiotic properties due to its allicin and other sulfur compounds (Tedeschi et al., 2007). Because the respiratory organs sometimes emit allicin, garlic is used to treat respiratory tract diseases. A patient with pulmonary gangrene was given garlic tincture by French phytotherapist Lecraec. The patient healed in 17 days (Petrovska & Cekovska, 2010). Garlic has been used as a therapeutic agent to address numerous cardiovascular and circulatory disorders, such as hypertension, elevated cholesterol, myocardial infarction, coronary artery disease, and arterial hardening (atherosclerosis), attributed to its biologically active compound allicin and its derivatives (Timbo et al., 2006).

Garlic aids in the prevention of various types of cancer, including lung, breast, stomach, bladder, prostate, colon, and rectal cancers. It also contributes to warding off tick bites, enhancing immune function, and treating as well as preventing bacterial and fungal infections (Amagase, 2006). The therapeutic benefits of garlic are also described. It can cure ailments like coughs, headaches, stomachaches, congestion, and rheumatism. In addition, it is employed to promote healthy liver function and alleviate stress and fatigue (Tesfaye & Mengesha, 2015). Herbalists throughout the world often recommend garlic as a remedy for intestinal parasites. Garlic enemas prepared from crushed cloves are given to children suffering from parasitic infections in some cultures. A traditional Chinese medicine for gastrointestinal disorders is a mix of alcohol with crushed garlic cloves. The anti-parasitic content of allicin can be aimed at major intestinal parasites in the human system, such as *Giardia lamblia*, *Ascaris lumbricoides*, and *Entamoeba histolytica* (Gebreyohannes & Gebreyohannes, 2013). *Entamoeba histolytica*, the intestinal protozoan parasite of man, is extremely sensitive to allicin, and with only 30 μg/ml of allicin, halted the growth of amoeba cultures (Mirelman, 1987). In addition, allicin decreased *E. histolytica* trophozoites' virulence by 90% at a dilute concentration (5 μg/ml) as indicated by their failure to injure tissue-cultured mammalian cell monolayers in vitro (Ankri et al., 1997).

Wound healing is dependent on angiogenesis, and diabetic and chronic wounds with poor vascular function display impaired angiogenesis. Employing macroscopic observation, histopathology, scanning electron microscopy (SEM), and computerized three-dimensional (3D) imaging methods, scientists compared the influence of AGS on wound closure, re-epithelialization, matrix repair in the skin, and angiogenesis (Jalali, 2009). Various animal studies validate garlic's capacity to decrease the level of blood glucose in diabetic mice and rats induced by alloxan and streptozotocin. The majority of the research showed that garlic aids in lowering blood glucose in diabetic mice, rabbits, and rats (Eidi et al., 2006). Hypertension can be treated effectively using garlic powder. Garlic extracts showed antihypertensive activity and had remarkable decreases in both SBP and DBP (Silagy & Neil, 1994). IT has been reported that garlic acts as a diuretic, which helps to get rid of body liquids (Ali, 1995)."

Different Techniques to Screen Phytochemicals

Enzyme-Assisted Extraction (EAE)

Enzymes like cellulase, pectinase, or hemicellulase are used in enzyme-assisted extraction (EAE) to break down cell walls and release intracellular phytochemicals. In EAE, a particular enzyme solution is combined with crushed garlic. By acting on the components of the garlic's cell wall, the enzymes facilitate the release of substances into the solution, including phenolic acids, flavonoids, and allicin. EAE has been demonstrated to boost the output of phenolics and other antioxidants and is especially good at protecting delicate molecules. The expensive cost of enzymes is a significant barrier to enzyme-assisted extraction, despite its benefits under mild circumstances, high efficiency, property maintenance, and extraction stability (Uwineza & Waśkiewicz, 2020).

Pressurized Liquid Extraction (PLE)

Technique that help to dissolve different bioactive compounds in the dissolving sopvents is PLE.This technique improves extraction by using high pressure to keep solvents liquid above their boiling point. Samples of garlic are put in a solvent-filled high-pressure chamber (Alarcon et al., 2023). Compounds such as organosulfur phytochemicals are successfully dissolved without being degraded by the solvent's extensive penetration into plant tissues under pressure. For quicker and cleaner extraction, PLE has been used more and more in the food and pharmaceutical sectors. This method works well for extracting thermolabile chemicals and is quick and environmentally friendly. Long extraction times, the requirement for a lot of organic solvent, and the possibility of thermolabile chemicals being destroyed are some disadvantages, though (Richter et al., 1996).

Pulsed Electric Field Extraction (PEF)

This technique mainly employed to obtain bioactive compounds or extract either from living or dead cell. In this, short, high-voltage pulses are used in pulsed electric field (PEF) extraction to puncture cell membranes and release intracellular substances. In a water-based medium, garlic is subjected to pulsed electric fields, which cause cell walls to permeabilize. Owing to use of this technique many phytochemicals like Allicin can be extracted through plant sources as it has property to penetrate inside. PEF maximizes yields while reducing heat degradation, making it especially well-suited for extracting delicate bioactive chemicals. Reversible membrane alterations and air bubbles that reduce process effectiveness are other drawbacks (Pardo et al., 2007).

Subcritical Water Extraction (SWE)

Liquid-based extractions are mostly done with the help of SWE. The method for this technique involves, under pressure, subcritical water extraction (SWE) uses water that is between 100°C and 374°C. This technique is very popular among chemists and researchers to obtain anti-oxidant compounds from any plant source (Herrero et al., 2006). In a pressurized chamber, subcritical water is used to treat garlic. Water's solvency is increased by the high temperature and pressure, which allows it to dissolve a range of phytochemicals, such as phenolic acids and flavonoids. Although it has several drawbacks that are challenging to automate and necessitate a lot of glassware, it is thought to be safer and more environmentally friendly than organic solvents because it employs water as a solvent (Herrero et al., 2006).

Deep Eutectic Solvent Extraction (DES)

Naturally occurring substances that form a liquid phase at low temperatures make up deep eutectic solvents (DES). When it comes to extracting phenolic and antioxidant components from garlic, DES are very adaptable, biodegradable, and efficient (Paiva et al., 2014). A DES solution intended to target particular phytochemicals is combined with garlic. The DES solution is a highly selective and environmentally friendly extraction process since it dissolves bioactive components like flavonoids and polyphenols. However, it has several drawbacks, such as flammability, toxicity, and environmental persistence (Paiva et al., 2019).

Cold Press Extraction

Garlic's natural profile of volatile and heat-sensitive components is preserved using cold press extraction, which removes oils and phytochemicals without the use of heat. In cold conditions, garlic is ground and compressed. Without changing their molecular structure, the mechanical pressing releases oils and other phytochemicals. Higher allicin levels are retained in cold-pressed garlic oil, which makes it advantageous for use in nutritional supplements. Some disadvantages include skin irritation and allergic responses (Paiva et al., 2019).

Maceration

Maceration, which requires immersing powdered plant material in solvents such as methanol, ethanol, ethyl acetate, acetone, hexane, etc., is one of the most fundamental extraction techniques. It is one of the popular and affordable ways to extract different bioactive compounds from plant material. Nevertheless, the maceration process has some drawbacks as such as a low extraction output, reduced effectiveness, and the use of numerous solvents that may be hazardous to one's health (Rashid et al., 2021).

Common Phytochemicals Found in Garlic

It was accessed by various studies that almost 33 sulfur containing compounds, vitamins, lipids, many enzymes, various minerals are preset in garlic. Along with these compounds, it yields almost 17 types of different amino acids. Some of them are lysine, histidine, serine, glycine, tryptophan and many others. The pungent smell and many medicinal qualities of garlic owe much to its greater content of sulfur compounds than other *Allium* species (Josling, 2005). Around 85% of the allicin and other cysteine sulfoxides in a garlic plant are contained in the bulb, 12% in leaves, and 2% in roots. Yet only bulbs have γ-glutamyl cysteines. Quercetin, the most common flavonoid found in garlic, is a highly effective antioxidant (KhokharVoytas et al., 2023). It has been associated with anti-inflammatory activity, cardiovascular benefits, and possible anticancer activity. Kaempferol is another significant flavonoid found in garlic that enhances its health-promoting effects (Xian et al., 2012).

Alliumin is a flavonoid specifically associated with garlic. It contributes to garlic's antimicrobial and anti-inflammatory effects (Xian et al., 2012). Apigenin is present in smaller amounts and it is a dietary flavonoid that can be found in a variety of plants, including kumquats, celery, parsley, basil, chamomile tea, and fruits and vegetables. According to experimental research, apigenin effectively suppresses tumors in both in vitro and in vivo situations against several cancer cell lines (Jeong & Jung, 2016). Additionally, phenolic chemicals, such as phenolic acids, which have strong antioxidant properties, are abundant in garlic. The redox action of phenolic compounds is what gives them the ability to antioxidant. Important antioxidants called phenolic acids shield the body from the damaging properties of free radicals (Goleniowski et al., 2013) In addition to volatile chemicals, garlic is high in antioxidants, flavonoids, minerals (particularly P, K, and Se), and vitamins (particularly B complex and C) (Rekowska & Skupień, 2009). The overall phenolic content, however, varies greatly across the different ecotypes and genotypes as well as between the growth circumstances and cultivation methods used (Volk & Stern, 2009). Garlic saponins play a part in reducing cholesterol levels and boosting immune responses (Pardo et al., 2007).

Antioxidant Activity of Allicin in Garlic

The application of Allicin as an anti-oxidative stress therapy gained much attention as its application has no side effects like many synthetic drugs have. (Jeong & Jung, 2016). Through their interaction with thiol-containing enzymes, a study emphasized the antioxidant efficacy of allicin and its precursor in the Fenton oxygen-radical generating system, as shown in Figure 1. The relationship indicates that allicin is capable of neutralizing toxic oxygen radicals and safeguarding cells from oxidative damage. Allicin has been attributed to have antioxidant effects since it is capable of inhibiting the activity of superoxide and hydroxyl radicals, two highly reactive species implicated in oxidative stress (Chung, 2006). Moreover, it has been found that allicin blocks the enzyme xanthine oxidase, which produces superoxides, probably by interacting with the thiol groups of the enzyme. This inhibitory action further reduces oxidative stress by lowering the production of reactive oxygen species (ROS). To minimize oxidative stress in cells, allicin may also influence the sulfhydryl group of thiol proteins or act as a precursor to certain biological agents (Xiao & Parkin, 2002). Chemical research shows that by decreasing the formation of conjugated diene hydrogen peroxide antioxidant molecules generated from ROS, allicin can effectively prevent lipid peroxidation. Okada Tanaka et al. (2005) This technique adds to the evidence that allicin protects lipids and cellular structures from oxidative damage (Okada et al., 2005).

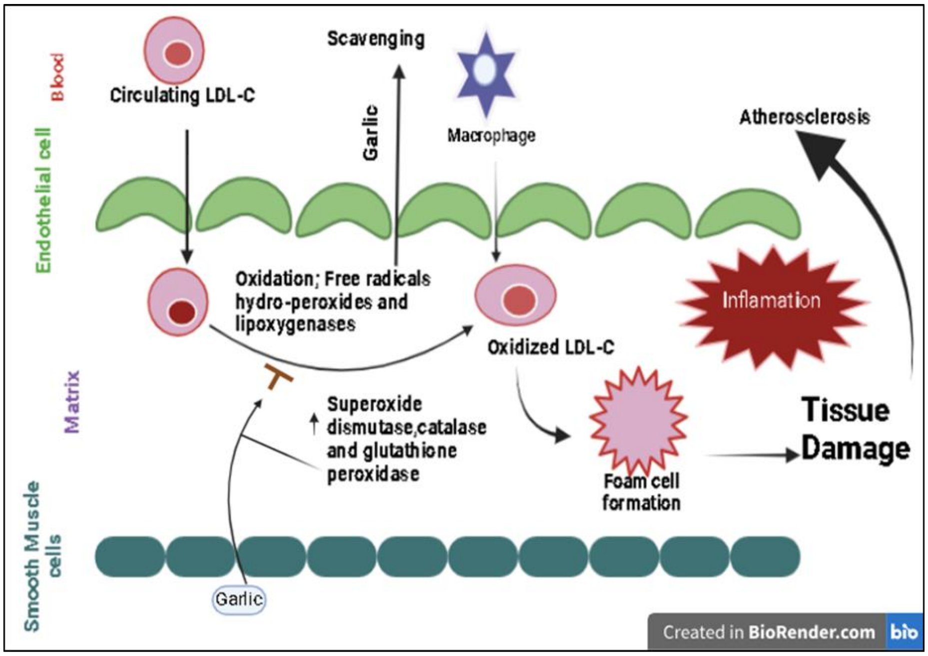

Fig. 1: Antioxidant mechanism: garlic protects endothelial cells from oxidized molecule damage by scavenging ROS

Glutathione and cysteine react with allicin to form S-allylmercaptoglutathione (SAMG) and S-allylmercaptocysteine (SAMC). These compounds are believed to have strong antioxidant properties, according to researchers. SAMG, SAMC, and allicin exhibit similar effects, providing further evidence of allicin's role in maintaining cell integrity under oxidative stress conditions (Horev-Azaria et al., 2009). *In vivo* models have demonstrated that allicin significantly reduces intracellular ROS content in the vital organ of the body, which is the heart, which is beneficial in diminishing oxidative stress under conditions such as ventricular hypertrophy, as summarized in Table 1. Additionally, *in vitro* experiments indicate that allicin can also reduce intracellular ROS in cardiac myocytes substantially, further proving its capacity to neutralize ROS and safeguard cells against oxidative stress. Moreover, it has been generally accepted that allicin is able to neutralize the very reactive 1, 1-diphenyl-2-picrylhydrazyl (DPPH) and hydroxyl radicals responsible for oxidative stress. (Ilić, Stojanović et al., 2015). ROS other scavenging molecules and protect cells from oxidative harm. Research suggests that the hydroxyl radical's capacity to neutralize free radicals may increase in direct relation to the concentration of allicin (Okada et al., 2005).

Table 1: Antioxidant activity of garlic extracted compound allicin.

Model	Concentration	Mechanism of Action	References
Hepatotoxicity induced in rats through arsenic trioxide	30 mg kg^{-1} i.p.	KLF9-mediated Nrf2 signaling pathway activation prevents oxidative damage and apoptosis.	(Yang et al., 2017)
Cardiac hypertrophy: Primary culture myo-cells and fibroblasts	10 μM	blocked ROS to inhibit the PI3K/Akt/GSK3β, JNK1/2, and ERK1/2 signaling pathways.	(Lawson, 1993)
Rat (mice) model	50 mg kg^{-1} p.o	Prevent fibrosis and inflammation by preventing the SMAD cascade from being activated by ROS and NF-κB.	(Lawson, 1993)
Primary culture of endothelial cells	10–20 μM	Reactive oxygen species damage can be avoided by increasing glutathione levels and turning on phase II detoxification enzymes.	(Horev-Azaria et al., 2009)
Diphenyl 1-1- picrylhydrazyl test	5.0 and 15 μg mL^{-1}	Strong -OH scavenging capabilities	(Li et al., 2017)
Diphenyl 1-1- picrylhydrazyl test	0.3 to 3 mg mL^{-1}	Maximum level of DPPH radical neutralization, minimal antiproliferative effect, and no cytotoxic effect on HeLa cells	(Ilić et al., 2015)
Oxygen radical generating system, Fenton	0.0003 μM	a modulator that uses thiol-disulfide exchange processes to regulate the enzymatic activity of enzymes containing SH.	(Ilić et al., 2015)
Analysis using P1 staining and Annexin V/P1 staining assays	10, 20, 40 μg mL^{-1}	The antiapoptotic action lowers MDA, raises SOD, and regulates pro-Caspase-3 levels.	(Chen et al., 2014)
Oxidation through methyl linoleate	10, 20 and 30 μM	scavenging free radicals and preventing lipid peroxidation.	(Okada et al., 2005)

Neutralization of Free Radicals

Both free radicals and non-radical species are considered ROS. Free radicals are unstable, reactive, and carry an unpaired electron. These consist of nitric oxide, superoxide, and the most hazardous and reactive ROS, the hydroxyl radical. Ozone, hydrogen peroxide, and singlet oxygen are examples of non-radical oxidants that, through a variety of chemical processes, produce free radicals in tissues (Gutteridge & Halliwell, 1993). Garlic extract has the ability to affect the expression of important angiogenic factors, such as vascular endothelial growth factor receptors (VEGFR). It may improve these factors' expression and stability by adjusting ROS levels, which would encourage angiogenesis. Garlic components have the potential to activate a number of signaling pathways that are impacted by ROS. In Figure 2, such as: NF-kβ Pathway: By reducing oxidative stress, garlic may lessen the activation of NF-kβ, leading to a balanced expression of angiogenic genes (Timbo et al., 2006). Mitogen-activated protein kinase (MAPK) pathway, where garlic can also modulate the MAPK signaling pathway, which is critical to endothelial cell proliferation and migration. HIF-1α Stabilization during hypoxia, garlic extract can stabilize HIF-1α, which plays a key role in the transcription of VEGFR and other pro-angiogenic factors, eventually driving angiogenesis. In cell migration and proliferation, garlic extract is reported to stimulate the proliferation and migration of endothelial cells, which are critical events in angiogenesis. These actions could be attributed to the regulation of ROS levels and enhancement of angiogenic signal pathways (Sanie-Jahromi et al., 2023).

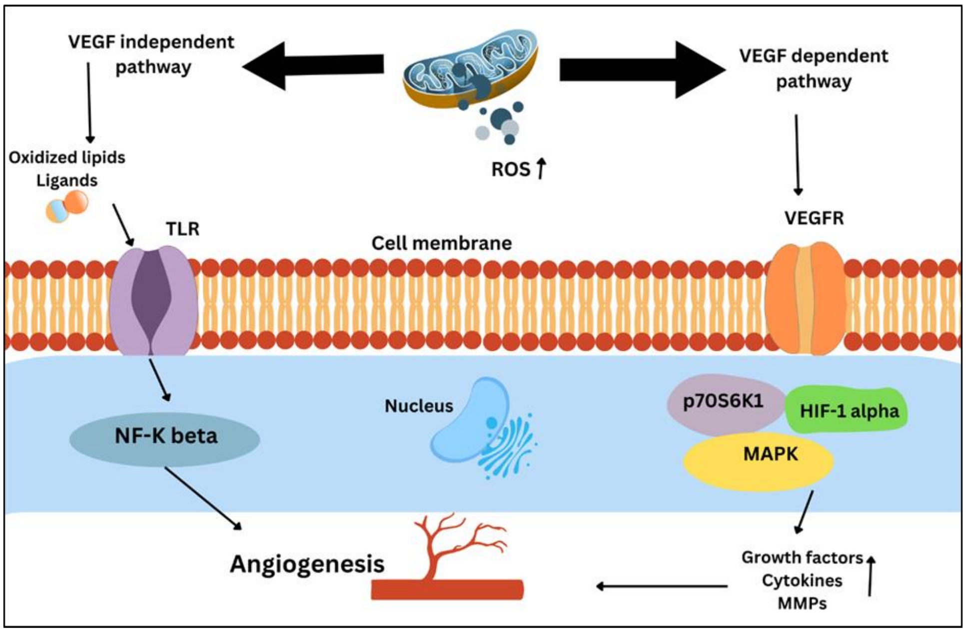

Fig. 2: Angiogenesis through the activation of reactive oxygen species (ROS)

Antimicrobial Activities of Garlic

One of garlic's most well-known qualities is its antimicrobial activity. It can suppress the growth of a broad spectrum of microorganisms, including bacteria, fungi, and viruses. Garlic functions as a broad-spectrum antibiotic, meaning it targets various types of pathogens. Garlic has the very broadest spectrum of any antimicrobial known to us today. This is due to allicin, a substance that is emitted when garlic cloves are chopped or pressed, as shown in Figure 2. Allicin, responsible for fresh garlic's spiky, pungent flavor, is also responsible for its long-term antimicrobial activity. This indicates that garlic, when applied externally or ingested, has powerful antimicrobial effects (Caporaso et al., 1983). Studies show that garlic can act effectively against gram-negative and gram-positive bacteria. Particularly, allicin inhibits bacteria growth and diffusion by destroying cell walls of the bacteria. Garlic has been proven as an effective organic remedy for infections caused by bacteria (Volk & Stern, 2009).

Anti-viral Activity

Garlic has traditionally been utilized as a herbal remedy to manage a variety of infectious illnesses, including the common cold, flu, and other viral infections (Lissiman et al., 2014). Comprehending the viral life cycle is crucial for antiviral drug development, as it helps identify possible therapeutic targets. It has exhibited anti-tumor effects, driven by immune responses involving tumor-specific T cells and the cytotoxic activity of CD^{8+} T cells. As illustrated in Figure 3, the viral-induced destruction of CD^{4+} T cells contributes to the gradual weakening of the immune system during the early stages of HIV infection (Okoye & Picker, 2013). Numerous studies have demonstrated that pure ajoene's immunomodulatory strategy to prevent HIV infection can shield CD^{+} cells from HIV attack. Ajoene may bind with the HIV-1 protein, according to molecular docking research, which would further substantiate its anti-HIV properties (Lissiman et al., 2014).

Anti-Fungal Activity

Garlic extracts exhibit strong antifungal properties and inhibit the synthesis of mycotoxins, such as aflatoxin produced by *Aspergillus parasiticus* (Eidi et al., 2006). Moreover, garlic extracts are highly antifungal and inhibit the mycotoxin synthesis, including aflatoxin of *Aspergillus parasiticus*. Allicin is also the most responsible compound for inhibiting fungal growth (Iqbal et al., 2025). High dose of garlic extract with almost 50% thiosulfate and 34% allicin showed rise in fungistatic and fungicidal activities *in vitro* against three different races of

Cryptococcus neoformans. Moreover, *in vitro* experiments indicated that amphotericin B had a synergistic fungistatic action on all *C. neoformans* isolates (Davis et al., 1994). Pure allicin was found to exhibit potent antifungal effects at a minimum inhibitory dose of 7 µg/mL (Hughes and Lawson 1991). Pure allicin exhibited activity *in vitro* against *Candida* species, *Cryptococcus* species, *Trichophyton* species, *Epidermophyton* species, and *Microsporum* species at low concentrations with minimum inhibitory concentrations from 1.57 to 6.25 µg/mL. Allicin inhibits spore germination and hyphal growth (Yamada & Azuma, 1977). A purified allicin formulation was shown to markedly enhance the susceptibility of several clinically important yeast strains. Although the exact mechanism of action of allicin on the fungal cell is yet unknown, it is thought to work on thiol enzymes, just like in other microbes, as mentioned in Table 2.

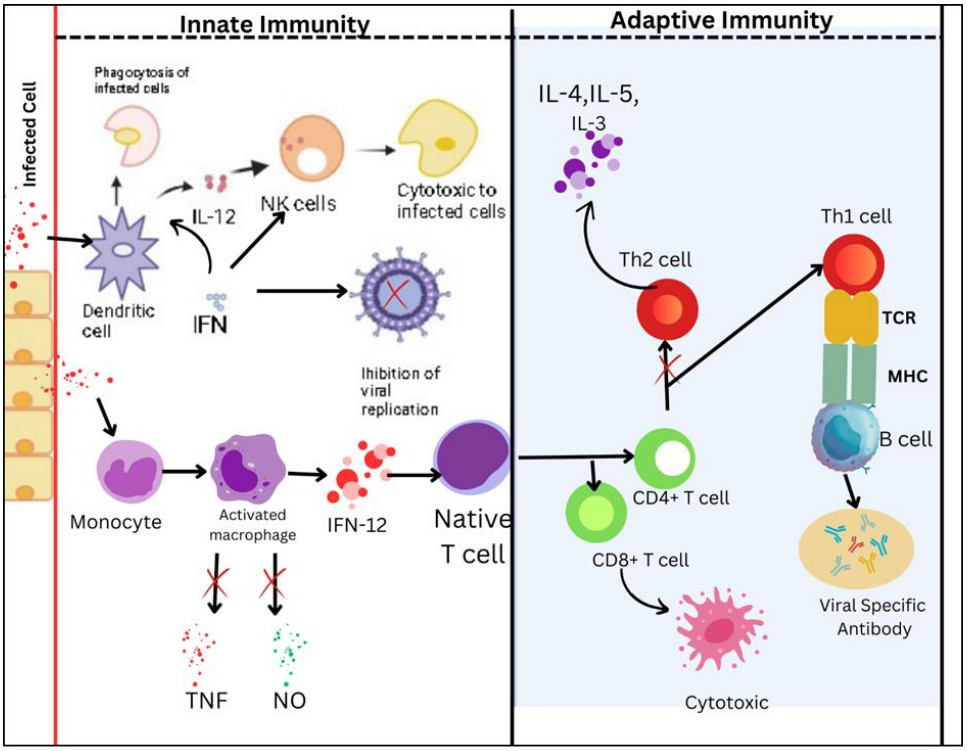

Fig. 3: A potential mechanism behind the immunomodulatory effects of garlic and its organosulfur compounds (OSCs) in hosts infected by viruses

Table 2: Effect of compound extracted from garlic 'allicin' on various fungal pathogens.

Fugal strain	Allicin Concentration	Results	Reference
Candida tropicalis	0.3	-	(Volk & Stern, 2009)
Candida parapsilosis	0.15	-	(Trofa et al., 2008)
Candida albicans	0.3	Clinical isolates	(Sudbery, 2011)
Candida neoformans	0.3	-	(Hull & Heitman, 2002)
Candida krusei	0.3	-	(Hull & Heitman, 2002)
Torulopsis glabrata	1.9	Clinical isolates	(Jeong & Jung, 2016)

Limitations of Garlic's Medicinal Use

Although garlic's potential health advantages are well known, there are a number of drawbacks to using it medicinally, as noted. Depending on the species, growing environment, and processing techniques, the active ingredients in garlic, including allicin, can differ greatly. Its effectiveness may be impacted by this heterogeneity (Petropoulos et al., 2018). Garlic's active components may have uneven absorption and metabolism due to bioavailability, which can have varying effects on different people (Lawson & Hunsaker, 2018). Not enough proof to support some claims, more thorough clinical trials are frequently required to validate these claims, even though garlic has been researched for a number of health benefits (Green-Gonzalez, 2020). Possible adverse effects that Garlic's use is restricted in some populations due to its potential to produce gastrointestinal distress, allergic responses, and interactions with certain drugs (such as anticoagulants) (Spolarich & Andrews, 2007). Garlic's general use as a medicinal food can be influenced by a variety of cultural and dietary factors, including how it is accepted and incorporated into dietary patterns (Piate & Harrison, 2023). Not a replacement for traditional medical care garlic can help with some treatments, but for serious ailments, it shouldn't be used in place of traditional medical treatments (Anderson et al., 1995).

Conclusion

Because of the antibacterial and antioxidant properties of garlic, it is a truly amazing medicinal herb that has many health benefits. Its diverse phytochemical composition, especially the sulfur-containing chemicals, makes it a powerful natural treatment for infections and oxidative stress. The entire potential of garlic in medicine is still a fascinating area of research. The ability of garlic as a natural antibacterial agent is also evidenced by the antimicrobial assays, which indicate its potent activity against a variety of pathogenic bacteria, particularly gram-positive bacteria. The findings corroborate the traditional uses of garlic in herbal medicine and indicate its potential for use in therapeutic and food preservation contexts. As our knowledge of the precise mechanisms behind these actions grows, there is an urgent need for more studies to identify and isolate individual chemicals, which may result in the creation of novel pharmaceuticals and health supplements. All things considered, garlic is a wonderful natural resource with potential use in avoiding illness and boosting health.

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