Journal of Population Therapeutics & Clinical Pharmacology

RESEARCH ARTICLE
DOI: 10.53555/jptcp.v29i04.3915

REVEALING THE PHYTOCHEMISTRY, PHARMACOLOGY AND TOXICOLOGY OF *ALLIUM SATIVUM* -A REVIEW

Anandarajagopal Kalusalingam[1*], Roshan S[2]

[1*]Research Scholar, Department of Pharmacy, Bir Tikendrajit University, Imphal, Manipur
[2]Research Supervisor, Department of Pharmacy, Bir Tikendrajit University, Imphal, Manipur

***Corresponding Author:** Anandarajagopal Kalusalingam
*E-mail: anandkarg@gmail.com; 0091-9789387828

Abstract

Allium sativum Linn, a member of the Amaryllidaceae family, commonly known as garlic, holds global significance as a herbal supplement. It is widely utilized for both the prevention and treatment of various diseases in different cultures. Garlic plays a prominent role in traditional medicinal systems, such as traditional Chinese medicine, Islamic medicine, folklore medicine, and the Indian Ayurvedic system, where it is recognized as an effective remedy for numerous human ailments. The objective of this study was to examine scientific articles exploring the therapeutic potential of *A. sativum*, with the aim of providing up-to-date and reliable scientific evidence to support the use of garlic in promoting human health and managing various health issues.The information underscores the natural gift that garlic offers to humanity. Based on the comprehensive data discussed, A. sativum has the potential to serve as a treatment for a wide range of ailments by inhibiting various bacteria, fungi, harmful viruses, and insects. Garlic's manifold therapeutic properties, including its antioxidative capacity, antidiabetic, antihyperlipidemic, thrombolytic, cardioprotective, hepatoprotective, neuroprotective, and potential anticancer effects, make it an exceptional natural remedy for a variety of health concerns. These effects can be attributed to the diverse array of bioactive compounds found in garlic, including alkaloids, flavonoids, phenolic compounds, and organosulfur compounds like allicin and ajoene. However, it is also important to carefully examine potential adverse effects and safety considerations. Further research is crucial to gain a comprehensive understanding of the mechanisms underlying garlic's effects to validate its potential health benefits for humans.

Keywords: *Alliumsativum*, garlic, review, phytochemistry, pharmacology, toxicology

INTRODUCTION

Nature has bestowed humanity with a wealth of therapeutic wisdom, rooted in the extensive array of medicinal plants. Unlike synthetic alternatives, herbal products are generally considered safe for both people and the environment. Over thousands of years, plants have been extensively studied for their medicinal properties, and traditional medicines continue to play a pivotal role in addressing health issues worldwide. Notably, more than 80% of third-world populations rely on natural products for their daily healthcare needs (Lawal et al., 2016).For millennia, humans have harnessed the healing properties of plant-based products, either in their natural state or as crude extracts, to combat various diseases. Dietary supplements play a substantial role in alleviating a wide range of human ailments, their significance varying across different cultures (Tesfaye, 2021b).

Modern medicine, while advantageous, also comes with its share of side effects. Consequently, plant-based products have gained popularity due to their perceived safety, accessibility, and cost-effectiveness. This has prompted a return to nature with approaches like phytotherapy, given that plant products are abundant sources of pharmaceutical compounds (Sasi et al., 2021). The growing reliance on nature-sourced medications has led to the extraction and development of numerous drugs and chemotherapeutic agents derived from traditional herbs, especially in tropical regions (Abubakar, 2009).

It is imperative to conduct research on both novel molecules and well-established resources to gain insights into fundamental biological aspects and disease treatment/prevention, leading to innovative therapeutic options. Many present-day drugs find their origins in medicinal plants, and various bioactive compounds derived from plants contribute to the development of new medicines (Isbilen & Volkan, 2021).Experimental studies are essential to demonstrate not only the pharmacological properties of plants but also to identify their active compounds. This is crucial to minimize the potential adverse effects stemming from the improper use of plants based solely on traditional folklore(Rempel, 2021). The surge in the popularity of alternative medicine and natural products has rekindled interest in garlic and its derivatives as potential natural remedies, whether consumed in crushed or encapsulated form, and this has gained global popularity (Fesseha & Goa, 2019).

Garlic, scientifically known as *Allium sativum* Linn (Family: Amaryllidaceae) is a globally significant herbal supplement used for both the prevention and treatment of various diseases across different societies(Shooriabi, 2021). With a history spanning over 4,000 years, garlic is one of the most extensively studied medicinal plants. It holds a special place in traditional medicinal systems, including traditional Chinese medicine, Islamic medicine, folklore medicine, and the Indian Ayurvedic system, where it is recognized for its properties like anti-thrombotic, hypolipidemic, and anti-hypertensive effects. In homeopathic medicine, garlic is regarded as an effective remedy for various ailments. Moreover, garlic extracts have been associated with antibiotic properties, hypoglycemic effects, antitumor potential, and antioxidant and antithrombotic benefits(Khorshed Alam et al., 2016). Based on the information provided, a systematic review on garlic was conductedto identify scientific articles exploring the therapeutic potential of A. sativumto provide current and reliable scientific evidence to enhance the use of garlic for the promotion of human health and the management of various diseases.

METHODOLOGY

In this review, scientific data regarding the therapeutic properties, phytoconstituentsand toxicity of A. sativum were collected from a range of literature databases, including PubMed, Elsevier's Science Direct, Springer, ResearchGate, and Google Scholar. The suitability of the articles for the research topic was evaluated by reviewing their titles and abstracts. Only scientific papers that were fully accessible in their entirety were incorporated into the analysis. Furthermore, the references cited in the selected articles were carefully examined by manual screening to ensure the accuracy and reliability of the content.

PHYTOCHEMISTRY OF A. SATIVUM

In a study focusing on phytochemical screening, the results indicated the presence of glycosides, cardiac glycosides, reducing sugar, alkaloids,flavonoids, tannins and phenolic compounds, saponins, amino acids, and triterpenoids in both the aqueous and methanolic extracts of garlic leaves and fully developed bulbs. However, fully developed garlic bulbs tested negative for reducing sugar in the study. The methanolic extract of undeveloped garlic bulbs exhibited positive results for all components except carbohydrates and flavonoids; it tested negative for these compounds. Similarly, garlic roots showed similar results to undeveloped garlic bulbs, except for flavonoids, which tested negative.(V. Singh & Kumar, 2017). The results of the qualitative phytochemical analysis of garlic reveal that both aqueous and ethanolic extracts of garlic contain saponin, alkaloids, tannin, steroids, flavonoids, lipids, ketones, and phlobutanins(Nazir & Chauhan, 2019). A similar preliminary

phytochemical study confirmed the presence of alkaloids, saponins, cardiac glycosides, steroids, and flavonoids in garlic, while tannins were absent. (Kiprop & Muthangya, n.d.).
The A. genus is well-known for its rich content of sulfur compounds, with garlic, in particular, containing around 33 of these compounds. The main biologically active component in garlic is allicin or diallyl thiosulfate. Recent focus has turned to polar compounds that display increased stability during cooking and storage, which includes flavonoids, saponins and sapogenins(Kovarovič et al., 2019).The medicinal properties of garlic often ascribed to its wealth of sulfur-containing compounds. Extensive research has explored the phytochemistry of garlic. Through the use of gas chromatography-mass spectrometry, various compounds were detected in garlic, including dimethyl trisulfide, diallyldisulfide, methyl allyl trisulfide, diallyltrisulfide, diallylsulfide, hexacontane, tetramethyl cyclotetrasiloxane, 2,4,6,8-tetramethyl-cyclotetrasiloxane,o ctadecamethyl cyclonona siloxane, guanosine, 1,2-benzenedicarboxylic acid, hexadecanoic acid, heptadecanoic acid, acetic acid, 4-hydroxy-1H-purine, 1H-purin-6-amine, and flavone 4'-OH, 5-OH, 7-di-O-glucoside. (Isbilen & Volkan, 2021).
The primary active components of garlic are its organosulfur compounds, which includediallylthiosulfonate (allicin), E/Z-ajoene, S-allyl-cysteine (SAC), S-allyl-cysteine sulfoxide (alliin), diallyltrisulfide (DATS),diallyldisulfide (DADS)anddiallylsulfide (DAS). The major phenolic compound in garlic is β-resorcylic acid, with other notable phenolic compounds being rutin, quercetin, gallic acid, pyrogallol, and protocatechuic acid (Shang et al., 2019).
Oils extracted from *A. sativum* using different distillation methodswere primarily found to consist of allyl polysulfides and this composition was determined using chromatography techniques. Notably, steam distillation yielded slightly higher amounts of diallyldisulfide and diallylsulfide, with a corresponding decrease in diallyltetrasulfide and diallyltrisulfide. It's important to highlight that these differences, while observable, were relatively small across the three distillation methods (Satyal et al., 2017).
In a recent study, the content of flavonoids and total phenols was evaluated using the aluminum chloride colorimetric and Folin-Ciocalteu methods, respectively. Gas chromatography was utilized to identify the chemical components of garlic essential oil. The findings revealed that the essential garlic oil contained a total phenol content equivalent to 0.53 mg of gallic acid per gram of essential oil, while the total flavonoid content was measured at 0.24 mg of quercetin per gram of essential oil. Remarkably, the concentration of diallyldisulfide in the mixture was found to be 40.3% higher. (Yasin et al., 2022).

PHARMACOLOGICAL ACTIVITIES OF A. SATIVUM

Medicinal plants have been continuously explored for the development of modern therapeutic agents. There have been extensive studies conducted on the pure compounds or extracts of to treat various disease. Table 2 shows the summary of pharmacological activities that had been reported from various part of *A. sativum*.

Anticancer activity

The study evaluated the cytotoxic effects of ASB extract on BCa cell lines using Trypan blue and LDH assays. Caspase-3 and -9 activity assays were conducted to understand the associated molecular pathways. Antiproliferative activity was determined via the MTT assay, and a lateral motility assay investigated BCa cell migration when exposed to ASB extract. The study shows that the ethanolic extract of A.sativum bulb has cytotoxic, antiproliferative, apoptotic, and anti-motility effects on both MCF-7 and MDA-MB-231 breast cancer cell lines, highlighting the anticancer potential of A.sativum L.'s bioactive molecules (Isbilen & Volkan, 2021).
The cytotoxicity of aqueous extracts from nine different garlic varieties originating from various countries, including Poland, Spain, China, Portugal, Burma, Thailand, and Uzbekistan, was assessed in vitro using the Neutral Red Uptake assay in normal human skin fibroblasts. Among these varieties, extracts from the Spanish cultivar Morado and Chinese garlic exhibited a high level of cytotoxicity,

causing a substantial reduction in cellular proliferation by approximately 70–90% (Szychowski et al., 2018).
A. extracts demonstrated dose-dependent inhibitory effects on both human normal cells (BJ and HaCaT) and tumor cells (DLD-1, MDA-MB-231, MCF-7, and SK-MES-1). At high concentrations, these extracts displayed cytotoxic effects on normal cells, evident through parameters such as the IC50 value, induction of necrosis, and measurements of LDH, catalase, and Caspase-3. Interestingly, the response to garlic extract varied among the four tumor cell lines, indicating differing levels of sensitivity. SK-MES-1 was the most sensitive, while MDA-MB-231 exhibited the lowest sensitivity, as determined by their respective IC50 values(Țigu et al., 2021).

Antimicrobial activity
Antimicrobial activity of extracts from dried garlic bulbs was tested against Staphylococcus aureus and Bacillus subtilis, Klebsiella pneumonia andEscherichia coli and the fungus Candida albicans. The methanol extract showed antimicrobial effectiveness against most microorganisms, except S. aureus and C. albicans. Hexane, chloroform, and ethyl acetate extracts displayed no antimicrobial activity. The minimum inhibitory concentration for the aqueous and methanol extracts against the tested bacteria and fungi ranged from 100-150 mcg/mL (Meriga et al., 2012).
Disc diffusion tests were performed to assess antimicrobial sensitivity on diarrheagenic pathogens present in stool samples, including Shigella species, Salmonella species, Proteus mirabilis and E. coli. The results demonstrated high sensitivity of these organisms to garlic, with ciprofloxacin (CPX) being particularly effective against E. coli. Variations in effectiveness were attributed to genetic differences and antibiotic mechanisms of action. Notably, none of the isolates exhibited resistance to garlic, indicating its potential as a potent antimicrobial agent. (Eja et al., 2007).
A study examined the antimicrobial effects of aqueous and ethanolic extracts from ginger (Zingiberofficinale Roscoe), garlic (A.sativum Linn.), and lime (Citrus aurantifolia Linn.) juice against various bacterial strains, including S. aureus, Bacillus species, E. coli, and Salmonella species. Notably, all test organisms were susceptible to undiluted lime juice. However, when tested individually, both ethanolicand aqueousextracts of ginger and garlic did not inhibit the growth of any test organisms. The most significant inhibition zonewas observed when a combination of these extracts was used against S. aureus. It's worth mentioning that Salmonella species showed resistance to nearly all extracts, except for lime juice(Onyeagba et al., 2004).

Antibacterial activity
An extract derived from garlic bulbs exhibited notable inhibitory activities against E. coli, K.pneumoniae, S. aureus, Psuedomonas aeruginosa, and Salmonella typhi. However, at a concentration of 80 mg/mL, the extract did not display inhibitory activities against S. typhi andK. pneumonia (Lawal et al., 2016).
The susceptibility of S. aureus was evaluated through the agar dilution method using clinical samples, including sputum, ear discharge, nasal swabs and stool. Biochemical tests, such as coagulase and catalase tests were conducted. MIC and MBC of garlic were determined against S. aureus, P. aeruginosa and E. coli and the results revealed that the antimicrobial properties of garlic (A.sativum) against S. aureus (Sheik & Ramamurthy, 2020).
The antibacterial activity of locally and imported garlic, which underwent thermal processing, was evaluated against Gram-positive bacteria, including S.aureus, methicillin-resistant S. aureus (MRSA) and B. subtilis, as well as Gram-negative bacteria, such as E. coli and Salmonella enteritidis using disc-diffusion method. The results indicated that the test samples demonstrated antibacterial effects against all the tested Gram-positive and Gram-negative bacteria. Notably, the freshest local garlic exhibited the most potent antimicrobial effects against all the tested bacterial species (Strika et al., 2017).
Aqueous and methanol extracts of garlic were evaluated against E. coli, K.pneumoniae, S. typhi, B. cereus, and Streptococcus mutans using the Agar well diffusion method. The results showed that the highest antibacterial activity was observed in the garlic aqueous extract against K. pneumoniae, while

the lowest activity was observed against S. typhi. It's worth noting that the percentage reduction in the growth of these test cultures was less pronounced after 4 hours, but their activity was more effectively reduced after 14 hours of exposure to the garlic extracts(P. Saravanan, V. Ramya, H. Sridhar, V. Balamurugan, 2010).

A study aimed to investigate the antibacterial activity of various extracts enriched with specific phytoconstituents from garlic against S. aureus, E. coli, and B. subtilis. The in vitro antibacterial activity of these extracts and garlic oil was assessed using the colony count method and estimated by the zone of inhibition method. The results revealed that garlic oil displayed notable antibacterial activity, particularly against MRSA(VISWANATHAN et al., 2014).

A study showed the antibacterial activity of a methanol extract derived from garlic against Lactobacillus using the agar well diffusion method. The results indicated that garlic exhibited growth inhibitory activity against Lactobacillus, and this inhibitory effect was dependent on the concentration of the garlic extract. Furthermore, the inhibitory effect significantly varied among the different concentrations tested (Kiprop & Muthangya, n.d.).

In a recent study, researchers investigated the antibacterial properties of ethanolic and aqueous extracts from A. sativum and A. porrum against Gram-positive and Gram-negative organisms from chronic wound infections. Using the agar well diffusion method, they tested ten isolates from open wounds, including, P. aeruginosa, S. aureus, K. pneumonia,E. coli and Enterococcus strains. Results showed A. sativum'sethanolic extract effectively inhibited most isolates, except one P. aeruginosa strain. A. porrum'sethanolic extract inhibited all bacteria except one E. coli and P. aeruginosa. Both extracts were effective against Gentamicin and Tetracycline-resistant S. aureus and K. pneumoniae. No synergistic effects were observed when the extracts were combined (Afunwa et al., 2022).

In another recent study, researchers explored the antibacterial activity of garlic essential oil against four bacterial strains: E. coli, P. aeruginosa, S. aureus, and Listeria innocua. The investigation involved assessing the minimum bactericidal concentration, minimum inhibitory concentration, and the disk diffusion technique. The study's findings indicated that among the tested bacteria, E. coli and P. aeruginosa were the most resistant to essential garlic oil (Yasin et al., 2022).

Antifungal activity

The growth and respiration of C. albicans are both sensitive to extracts ofgarlic because of the presence of allyl alcohol (AA). This sensitivity is associated with various observed effects, including NADH oxidation, glutathione depletion, and an increase in reactive oxygen species. These effects were detected using photon laser scanning microscopy and flow cytometry. It's worth noting that allyl alcohol (AA) is known to target alcohol dehydrogenases Adh1 and Adh2 (located in the cytosol) as well as Adh3 (found in the mitochondria). However, the significant decrease in NAD(P)H levels after the addition of AA suggests that there may be another mechanism of action contributing to its antifungal effect (Lemar et al., 2005).

The antifungal activity of locally and imported garlic, which had undergone thermal processing, was evaluated against the fungus C. albicans using the disc-diffusion method. The results indicated that the test samples exhibited fungistatic effects, meaning they inhibited the growth of the fungus without completely killing it.These findings suggest that preparations based on garlic could potentially be introduced into clinical practice for the treatment of infections caused by C.albicans(Strika et al., 2017).

In an another study, petroleum ether, methanol, and aqueous extracts from garlic were tested against C. albicans, Aspergillus niger, A. flavus, and Curvularialunata using cup diffusion and agar-incorporated methods. Antifungal activity was measured by inhibition zone diameter (mm). Results showed stronger and broader antifungal effects in aqueous and petroleum ether extracts compared to methanol. Interestingly, dry, coarsely powdered garlic exhibited higher potency against C. albicans. (Suleiman & Abdallah, 2014).

Antiviral activity

A study examined the relationships the effect of garlic between various immune system parameters, including peroxisome proliferator-activated receptor-gamma, adenosine monophosphate-activated protein kinase, andleptin, leptin receptor. Leptin, a proinflammatory hormone linked to appetite regulation, may play a role in COVID-19 symptoms. Garlic's potential to reduce the concentration of this proinflammatory hormone suggests it may help mitigate certain COVID-19-related symptoms. In summary, garlic could potentially act as a preventive measure against COVID-19 by boosting immune system activity and reducing the production of proinflammatory cytokines, such as leptin. It seems to counteract some of the detrimental effects caused by the virus. Incorporating garlic into one's diet as a preventive measure may help reduce viral spread in the body and enhance the immune system's ability to combat the pathogen (Donma & Donma, 2020).

An another review on garlic discusses its antiviral properties and the involvement of its organosulfur compounds (OSCs) in both pre-clinical and clinical research. It underscores the various mechanisms responsible for these effects. The primary pathways for garlic's antiviral activity, facilitated by its OSCs, encompass impeding viral entry and fusion with host cells, inhibiting viral RNA polymerase and reverse transcriptase, suppressing viral replication, and boosting the host's immune response.(Rouf et al., 2020).

Antimycobacterial Activity

A study was conducted to investigate the in vitro antimycobacterial activity of various extracts containing specific phytoconstituents from garlic. The assessment of in vitro antimycobacterial activity of different garlic extracts was performed using the Resazurinmicrotire plate assay technique. Extracts of garlic that were rich in allicin and ajoene demonstrated significant antimycobacterial activity in comparison to standard drugs (VISWANATHAN et al., 2014).

Anthelmintic activity

A syudyinvestigatd that methanol extracts from garlic (A. sativum), ginger (Z. officinale), Mexican pumpkin (C. mexicana), and sacred fig (F. religiosa) were tested for anthelmintic activity against Haemonchuscontortus. Z. officinale killed all worms within two hours (100% effectiveness). A. sativum and C. mexicana were equally effective at 2 and 4 hours, but by 6 hours, A. sativum reached 100% effectiveness, while C. mexicana achieved 83.4%. F. religiosa was 100% effective by 4 hours, similar to A. sativum and Z. officinale by 6 hours. (Iqbal et al., 2001).

Immunomodulatory activity

A review on the immunomodulatory activity of garlic has indicated that it can boost the innate immune response through the activation of macrophages and natural killer (NK) cells. It also enhances adaptive immunity by promoting the function of T cells and B cells. Additionally, garlic has been shown to stimulate the production of anti-inflammatory cytokines, which can help regulate the immune response (Rouf et al., 2020).

A previous study discovered that heat-extracts of black garlic were rich in S-allyl-L-cysteine (SAC) and exhibited potent anti-tumor activity, achieving a 50% cure rate in BALB/c mouse fibrosarcoma. Nevertheless, the precise mechanism behind this activity remained unresolved. To elucidate the anti-tumor mechanisms, experiments were conducted using a spleen cell culture system derived from mice treated with black garlic extracts. The black garlic extracts were found to enhance cellular immunity by increasing the activity of natural killer cells (NK cells), which are believed to play a pivotal role in eradicating tumor cells in vivo. Furthermore, the extracts led to the preferential generation of cytokines, including nitric oxide (NO), interferon-γ (IFN-γ), interleukin-2 (IL-2), and tumor necrosis factor-α (TNF-α), from the spleen cells of treated mice. Nevertheless, the levels of interleukin-4 (IL-4), which play a role in humoral immunity by contributing to the production of antibodies like IgG and IgE, decreased in the culture supernatants of spleen cells (Wang et al., 2010).

Insecticidal activity

Hexane, chloroform, ethyl acetate, methanol, and aqueous extracts obtained from the dried bulbs of A.sativum (garlic) were assessed for their insecticidal activity against the larvae of Spodopteralitura at a concentration of 1000 ppm. Among the extracts, the aqueous and methanol extracts exhibited the highest insecticidal activity, causing a mortality rate of 81% and 64%, respectively, among the larvae of S. litura. Further study of the bioactive molecules within the extracts of A. sativum can provide a deeper understanding of the insecticidal properties of these compounds (Meriga et al., 2012).

Antiparasitic activity

A study on the antiparasitic effect of dry powdered garlic pulp on Schistosomamansoni infected Swiss male albino mice investigated various biochemical parameters. Immunological parameters (IgM, IgG, IL-2, IL-6, and TNF-α) and antioxidant enzymes (catalase, SOD, and GPX) were evaluated. In mice infected with S. mansoni, there was an increase in IgG, IgM, IL-2, IL-6, TNF-α, and catalase levels, coupled with a decrease in GPX and SOD activities. Administration of garlic powder significantly improved all measured parameters in the infected mice. Furthermore, there was a notable reduction in worm burden, hepatic and intestinal eggs, and oogram count, leading to the normalization of liver architecture. This suggests that garlic may have potential antiparasitic effects and can help mitigate the biochemical and histopathological alterations induced by S. mansoni infection (Mona et al., 2011).

Antioxidant activity

A study investigated the effects of different forms of A. sativum on antioxidant activity in Nile tilapia (Oreochromisniloticus). The fish were fed with natural garlic, garlic oil capsules, and garlic powder tablets. The results showed significant improvements in final weight, weight gain, and specific growth rate (SGR) in all groups treated with A.sativum. The activities of antioxidant enzymes such as GPX, SOD, and CAT significantly increased compared to the control group. Malonyldialdehyde (MDA) levels, as well as the activities of alkaline phosphatase (ALP), aspartate aminotransferase (AST), and alanine aminotransferase (ALT) in plasma, significantly decreased in all garlic-treated groups. Total protein levels in blood serum significantly increased, while blood glucose, triglycerides, and cholesterol levels significantly decreased in the garlic-treated groups. The results suggested that A. sativummay stabilize cell membranes and protect the liver against harmful agents and free radical-mediated toxic damage. Additionally, the fish fed with garlic-containing diets exhibited the highest growth performance. Overall, the study concluded that garlic supplementation improved growth performance and protected cells against the effects of oxidative substances in Nile tilapia (Metwally, 2009).

A study investigated the antioxidant activity of raw garlic extract was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) scavenging method. This method involves observing a color change from deep violet to yellow, which indicates the antioxidant activity of the sample. The results of the DPPH scavenging analysis suggest that raw garlic can indeed serve as a source of antioxidants, as it demonstrated the ability to scavenge the DPPH free radicals, thereby reducing their activity and changing the color from violet to yellow. This highlights the potential antioxidant properties of raw garlic (Islamic, 2012).

A study investigated the antioxidant properties of A. sativum bulb extracts using DPPH to measure free radical inhibition. Aqueous and methanol extracts exhibited robust antioxidant activity, ranging from 80% to 90%, compared to a standard antioxidant. In the reducing power assay, methanol and aqueous extracts demonstrated antioxidant activity similar to ascorbic acid. These findings affirm the high antioxidant levels in garlic extracts, contributing significantly to the health benefits associated with A. sativum(Meriga et al., 2012).

The total antioxidant capacity of different parts of A. sativumwas evaluated using the phosphomolybdenum reduction assay method. The results indicated that all parts of the garlic plant exhibited antioxidant activity. This suggests that various parts of garlic contain compounds with antioxidant properties, which can help neutralize harmful free radicals and oxidative stress in the body (V. Singh & Kumar, 2017).

An another study demonstrated the quality of fillets was assessed based on various parameters, including pH, total volatile basic nitrogen (TVB-N), Thiobarbituric acid (TBA), aerobic bacteria (AB), psychrophilic bacteria (PB), lactic acid bacteria (LAB), yeast-mold counts, and organoleptic characteristics. The shelf life of the products was determined by monitoring the growth of AB, PB, LAB, and yeast-mold counts. The results showed that the fillets not treated with garlic essential oils experienced significant quality deterioration after 6 days of storage. In contrast, fillets treated with garlic essential oil, especially at a concentration of 4%, exhibited better control of quality changes during the fillets' shelf life. This was evidenced by lower TVB-N and TBA values and better organoleptic scores. Overall, the study demonstrated that garlic essential oil, as a natural antimicrobial and antioxidant agent, can be effectively used to extend the shelf life of O. mykiss (rainbow trout) fillets and potentially for preserving other food products as well (Kuzgun, 2019).
A study investigated the effects of microencapsulated A. sativum extract on rainbow trout juveniles' growth, immune response, and antioxidant status. Fish fed the extract showed improved growth performance and lower feed conversion ratio (FCR). They also exhibited higher protein and lower lipid content. Moreover, the fish had increased total serum protein levels and lysozyme activity, along with reduced liver enzyme activities (ALP, AST, ALT). Additionally, the fish displayed enhanced antioxidant status, indicated by higher SOD and catalase (CAT) activities. These results highlight the positive impact of garlic extract supplementation on rainbow trout juveniles' growth, immune system, and antioxidant defenses. (Adineh et al., 2020).
The antioxidant properties of aqueous extracts from different garlic varieties from various countries were evaluated using various methods. The results showed that the garlic extracts contained a significant amount of syringic and p-hydroxybenzoic acid derivatives. The Chinese garlic extracts exhibited the most potent antioxidant activity with the lowest IC50 values for scavenging DPPH• and ABTS•+ free radicals, as well as for chelating Cu2+ ions. Specifically, the IC50 values for Chinese garlic extracts were 4.63 μg/mL for DPPH• scavenging, 0.43 μg/mL for ABTS•+ scavenging, and 14.90 μg/mL for Cu2+ chelation. These findings indicate that Chinese garlic had the highest antioxidant capacity among the tested garlic varieties.(Szychowski et al., 2018)
Another study assessed the antioxidant potential of a methanolic extract of A.sativum (garlic cloves) using the DPPH assay. The results showed that the garlic extract exhibited antioxidant activity, and this activity was dose-dependent, meaning that higher concentrations of the extract had a more significant antioxidant effect. This suggests that garlic may help combat oxidative stress by scavenging free radicals and reducing their harmful effects on the body (Ullah et al., 2022).In another recent study, antioxidant content was assessed using the radical reduction capacity method, and the results indicated that the antioxidant activity, measured by the percentage of DPPH free radical scavenging, reached 80%(Yasin et al., 2022).

Wound healing activity

The study investigated the protective and anti-inflammatory effects of A. sativum oil in a rat model of corrosive esophageal burn. Corrosive burns were induced using sodium hydroxide, and the rats were treated with garlic oil either topically or systemically. The results showed that treatment with garlic oil led to a reduction in tissue damage, as evidenced by lower hydroxyproline levels, decreased stenosis index (SI), and histopathological damage score (HDS) in the esophagus. The study also found differences in the levels of TNF-α, an inflammatory marker, between the treatment groups and the control group. Systemic treatment with garlic oil had an anti-inflammatory effect, while topical treatment was more effective in reducing stenosis and tissue damage. These findings indicate that garlic oil could be a valuable therapeutic agent for promoting the regression of esophageal stenosis and reducing tissue damage caused by corrosive burns. The choice of application method, whether topical or systemic, may influence whether its protective or anti-inflammatory effects are more prominent (Tanrıkulu et al., 2017).

Antihyperlipidemic activity

The study investigated the antihyperlipidemic effect and potential curative properties of garlic (A.sativum) in guinea pigs with hyperlipidemia. After inducing hyperlipidemia in the guinea pigs for 4 weeks, they were fed with homogenized A.sativum daily for another 4 weeks. Blood samples were obtained at the study's outset, after 4 weeks, and upon completion of the 8-week period for the analysis of serum triglycerides, serum cholesterol, LDL-C, HDL-C, VLDL-C, and the atherogenic index. At the end of the 8-week period, all animals were euthanized, and the atherosclerotic lesions were assessed. The results showed that A.sativum exhibited a significant hypolipidemic effect, reducing serum cholesterol, triglycerides, LDL-C, and the atherogenic index in hyperlipidemic guinea pigs. However, there was no significant increase observed in HDL-C levels. This suggests that garlic has potential antihyperlipidemic properties and could be beneficial in reducing the risk of atherosclerosis in individuals with hyperlipidemia(Choudhary, 2008).
Another study focused on evaluating the impact of consuming raw garlic on reducing cholesterol levels in individuals with hypercholesterolemia in BabatJerawat village, Benowo Surabaya. Garlic consumption served as the independent variable, while the reduction in blood cholesterol levels was the dependent variable. Purposive sampling was employed as the sampling technique. The findings revealed a significant decrease in cholesterol levels in the blood, indicating the positive effect of garlic consumption on lowering cholesterol (Maisaroh et al., 2020).

Antidiabetic activity
A study aimed to assess the preventive and curative effects of methanol extracts from the outer scales and edible portions of A.sativum in induced Diabetic Neuropathy (DN) in Swiss albino mice. The extracts were administered daily at a dose of 200 mg/kg orally for 21 days, either prior to the onset of DN in the preventive group or after the onset of DN in the curative group. The mice induced with STZ-diabetes exhibited significant thermal hyperalgesia, indicating the development of DN. The results indicated that treatment with the test extracts prevented body weight loss, reduced plasma glucose levels, and significantly ameliorated hyperalgesia. Additionally, the extracts reduced thiobarbituric acid reactive substances (TBARS), serum nitrite, and increased reduced glutathione (GSH) levels in diabetic mice. These findings suggest that the methanol extracts of A.sativum have potential preventive and curative effects against diabetic neuropathy, potentially attributed to their antioxidant properties and their ability to modulate hyperglycemia(Bhanot & Shri, 2010).

Thrombolytic activity
A study explored the potential of garlic filtrate as an alternative anticoagulant in blood samples from 16 individuals. Using the Lee and White method, non-anticoagulated blood displayed a normal clotting time, averaging 8 minutes and 56 seconds. Conversely, both heparin plasma and garlic filtrate plasma showed significantly prolonged clotting times, exceeding 20 minutes, and this difference was statistically significant based on the Friedman test. Spectrophotometric measurements indicated that calcium ion levels in heparinized plasma and serum were approximately 8.66 mg/dL and 8.52 mg/dL, respectively. In garlic filtrate plasma, at concentrations of 50 μL/mL and 100 μL/mL, calcium ion levels were notably lower, measuring around 4.13 mg/dL and 3.58 mg/dL, respectively.This difference was statistically significant as well, as indicated by the ANOVA test. These findings suggest that garlic filtrate has the capacity to prolong clotting time and reduce calcium ion levels(Nuswantoro & Berlianti, 2022).

Cardioprotective
In a study on rats with isoprenaline-induced myocardial infarction, researchers explored the cardioprotective effects of garlic oil (GO) and its main component, diallyldisulfide (DADS), when used alongside carvedilol (CAR). Rats were divided into various groups and received GO, DADS, CAR, or a combination of these treatments along with isoprenaline. After 14 days, blood samples were taken, and heart tissue was analyzed for antioxidant enzyme activities, cardiac marker levels, and inflammatory markers. The results showed that rats receiving GO, DADS, and CAR had increased cardiac antioxidant enzyme activities and decreased levels of cardiac marker enzymes and

inflammatory markers. Combining CAR with GO or DADS enhanced these cardioprotective effects. Both DADS and GO had similar efficacy, suggesting DADS played a key role in garlic oil's cardioprotective properties. This combined treatment protected rats from ISO-induced myocardial infarction (Asdaq et al., 2021).

In a 4-week study, the potential cardioprotective effects of garlic (G) were explored in male albino rats exposed to sodium fluoride (NaF). Rats treated with NaF exhibited significant increases in cardiac markers such as serum creatinine kinase (CK), creatine kinase-MB (CK-MB), lactate dehydrogenase (LDH), aspartate aminotransferase (AST), alanine aminotransferase (ALT), and cardiac troponin I (cTnI). Additionally, there were notable elevations in total cholesterol (TC), triglycerides (TAG), low-density lipoprotein (LDL-c) levels, and atherogenic indicators (mean TC/LDL-c and LDL-c/high-density lipoprotein HDL-c ratios), along with a significant reduction in HDL-c levels in the NaF-treated group compared to the control rats. Treatment with G+NaF effectively improved all assessed biochemical parameters, indicating that garlic exerts a cardioprotective influence against NaF-induced cardiotoxicity (Abdel-Baky & Abdel-Rahman, 2020).

Neuroprotective

In a study investigating the protective effects of mycotoxin-free onion and garlic extracts on a rat model of Alzheimer's disease (AD), various groups of AD-induced rats were orally given 1, 2, and 3 mg/kg doses of onion or garlic extract for 30 days. Subsequent to the treatment period, the study conducted histopathological analysis, examined the expression of genes related to apoptosis, and assessed DNA damage and the generation of reactive oxygen species (ROS) in brain tissues. The results revealed that the administration of different doses of onion and garlic root extracts to AD-induced rats led to reduced histopathological damage, decreased expression of apoptotic genes, lower levels of DNA damage, and inhibited intracellular ROS production in brain tissues. These findings suggest that the protective effects of onion root extract against neurodegenerative damage may be attributed to its flavonoids and related compounds, which enhance antioxidant capacity and regulate gene expression patterns. (Hegazy et al., 2022).

In a study, the effects of aged garlic extract (AGE) and S-allyl cysteine (SAC) on Aβ25-35-induced apoptosis and ROS generation in PC12 cells were investigated. PC12 cells were cultured in a specific medium and pre-treated with AGE or SAC for 24 hours before Aβ25-35 exposure. The study assessed cell viability, DNA fragmentation, apoptosis, caspase activity, and ROS production. The results revealed that Aβ25-35 triggered apoptosis in PC12 cells, marked by a dose-dependent decline in cell viability, an increase in apoptotic cells over time, DNA fragmentation, and enhanced caspase-3 activity and PARP cleavage. Importantly, an increase in ROS levels preceded apoptosis onset upon Aβ25-35 exposure. AGE and SAC not only reduced ROS generation but also mitigated caspase-3 activation, DNA fragmentation, and PARP cleavage, offering protection against Aβ-induced apoptosis. These findings suggest ROS's involvement in Aβ-induced apoptosis in PC12 cells and highlight garlic compounds' potential to reduce apoptosis, possibly by enhancing the body's natural antioxidant defences(Peng et al., 2002) .

Hepatoprotective

A study investigated the hepatoprotective effects of different black garlic extracts against carbon tetrachloride (CCl_4)-induced acute hepatic injury (AHI) in mice. The n-butanol extract (BA) and water extract (WS) were found to have hepatoprotective properties, reducing AST, ALT, ALP, and hepatic malondialdehyde (MDA) levels. Additionally, these extracts increased the activity of SOD, GPX, glutathione reductase (GSH-Rd), as well as liver levels of TNF-α and IL-1β (Tsai et al., 2019)

An another study explored the hepatoprotective mechanisms of garlic extract in Carbon tetrachloride (CCl_4) intoxicated animals through both in vivo and in vitro assays. In vitro experiments revealed that the garlic extract demonstrated significant antioxidant and anti-inflammatory potential, inhibiting 67.5% of free radicals and 71.36% of albumin denaturation at 600 μg/mL concentration. After eight weeks of treatment with garlic extract, the study observed a notable reduction in serum ALT, ALP, and AST levels compared to the disease control group, which exhibited elevated levels. Moreover, CCl4-induced animals displayed decreased levels of SOD, GPX and GSH, while garlic extract treatment significantly increased these antioxidant enzymes. Additionally, pro-inflammatory markers such as C-reactive protein (CRP), TNF-α, IL-1β, IL-6, and Intercellular Adhesion Molecule 1 (ICAM-1) were elevated in CCl4-induced animals but reduced significantly with garlic extract treatment. Histological analysis showed improvements in hepatocyte architecture in animals treated with garlic extract along with CCl4, compared to those exposed to CCl4 alone, which exhibited lymphocyte infiltration, edema, and congestion(Almatroodi et al., 2020).

Enhancing Body Weight

A study combined garlic and copper in chick diets, yielding positive results. The treated chicks gained significant body weight compared to the control group, with a 10% better food conversion rate, indicating efficient feed utilization. The birds' health remained good, showing no adverse effects from these dietary additions. Regarding carcass quality, treatment diets didn't significantly affect yield or valuable carcass parts. In summary, adding garlic and copper to chick diets significantly boosted body mass, improving growth and production efficiency over the 42-day study(Stanaćev et al., 2011).

In another study, the effects of different garlic (A.sativum) supplementation levels on goldfish (Carassiusauratus) growth, survival, and nutrition were examined. Goldfish initially consumed a basal diet for one week, followed by experimental diets with varying garlic powder concentrations for eight weeks: 0 (Control), 0.5, 1, and 1.5 mg/kg. Results indicated no significant differences in growth and feed efficiency, with a slight advantage seen at the 0.5% level. However, survival rates were notably higher in the 0.5% garlic powder group, significantly outperforming the control diet. Thus, goldfish fed the 0.5% garlic powder diet demonstrated the best overall combination of growth, feed efficiency, and survival in the study(Sh et al., 2019).

TOXICOLOGY OF A. SATIVUM

A study examined the effects of single and combined oral administration of fresh aqueous extracts of onion (A. cepa) and garlic (A. sativum) in male albino rats. The extracts, given at 200mg/kg/day, led to significant increases in red blood cell count (RBC), packed cell volume (PCV), hemoglobin concentration (HGB), total white blood cell count (TWBC), neutrophil (NEUT) count, lymphocyte (LYM) count, and platelet count (PLT). Liver enzymes ALT and AST levels were significantly decreased, indicating potential hepatoprotective effects. Liver weight (LW) showed a non-significant dose-dependent reduction. There was no synergistic effect observed on hematological parameters when the two extracts were combined. The study suggests the hematological benefits of onion and garlic extracts without hepatotoxicity(Samson, 2012).

While garlic organosulfur compounds are generally considered beneficial for health, prolonged and excessive consumption of these compounds may lead to toxicity and adverse effects. This suggests that these phytocompounds may have dual biological functions, with both beneficial and potentially harmful effects. It's important to consume garlic and its organosulfur compounds in moderation to avoid any adverse health effects (Morales-González et al., 2019).

In a toxicological study using a rat model, the examined extract did not significantly alter several serum parameters, including enzymes and blood cell counts. However, notable effects were observed at higher doses (600 and 1200 mg/kg). These doses led to lowered levels of serum ALT, total proteins, direct bilirubins, chloride concentrations, and body weight gain. Conversely, concentrations of urea, albumin, white blood cells, mean corpuscular hemoglobin, and mean corpuscular volume count increased significantly with these higher doses. At a lower dose (300 mg/kg), mild alterations were observed in chloride, urea, and albumin levels. These results highlight dose-dependent effects, with higher doses causing more pronounced changes in certain serum markers(Lawal et al., 2016).

The genoprotective potential of garlic has been a subject of numerous studies, with the consensus suggesting that this property can be attributed to the interaction of various phytocomponents present in garlic. Some of the principal phytochemicals responsible for these effects include allicin, ajoene, DAS, DADS, DATS, γ-glutamyl SAC, and S-allylmercaptocysteine (SAMC). The combined action of these compounds contributes to garlic's genoprotective properties. There is potential for further scientific exploration and analysis in this area, particularly in understanding the specific mechanisms underlying the genoprotective effects of these individual phytochemicals and their interactions within garlic (Morales-González et al., 2019).

DISCUSSION

The antibacterial activity of garlic is primarily attributed to its oil-soluble organosulfur compounds, which include allyl sulphides,ajoenes andallicin. These compounds exhibit various antibacterial properties, including bactericidal effects, the ability to inhibit biofilm formation, neutralization of bacterial toxins, and interference with bacterial quorum sensing mechanisms. Garlic's organosulfur compounds are effective against a wide range of bacteria, even those that are multi-drug resistant (MDR). The mechanism of action involves the formation of disulfide bonds with free sulfhydryl groups in bacterial enzymes, which can compromise the integrity of the bacterial membrane and ultimately lead to bacterial cell death. This diverse range of antibacterial properties makes garlic a promising natural remedy in the fight against bacterial infections(Bhatwalkar et al., 2021).

The antibacterial activity of garlic, particularly attributed to allicin, operates through various mechanisms that disrupt bacterial functions. Allicin can interfere with RNA production, which is essential for protein synthesis. When RNA synthesis is impeded, bacteria cannot generate messenger RNA (mRNA), ribosomal RNA (rRNA), and transfer RNA (tRNA), leading to the cessation of protein production at different stages. Proteins are crucial for numerous cellular functions and the structure of the bacterial cell. Additionally, the disruption of lipid synthesis by allicin can have a profound impact on bacterial cell membranes and walls. Allicin interferes with the synthesis of components like phospholipids, which are crucial for the proper formation of cell membranes. When these processes are disrupted, the integrity of microbial cell walls is compromised, leading to cell lysis and bacterial death. Overall, the multifaceted action of allicin and other phytochemicals in garlic makes it effective against a wide range of bacteria by disrupting various vital cellular processes(Meriga et al., 2012).

Indeed, allicin and its derivatives, such as ajoene, allitridin, and garlicin, are among the organosulfur compounds (OSCs) found in garlic responsible for its antiviral properties. These OSCs play a key role in various therapeutic activities of garlic, including its ability to prevent viral infections. Both in vitro and in vivo studies have demonstrated the antiviral potential of garlic and its OSCs against a broad spectrum of viruses, including those affecting humans, animals, and plants. The mechanisms by which garlic and its OSCs exhibit antiviral activity include: Blocking viral entry into host cells, Inhibiting viral RNA polymerase, Inhibiting viral reverse transcriptase and DNA synthesis, Reducing the transcription of immediate-early gene 1 (IEG1), Downregulating signaling pathways like the extracellular-signal-regulated kinase (ERK)/mitogen-activated protein kinase (MAPK) pathway and Alleviating viral infections through immunomodulatory effects, thus enhancing the immune response. Clinical studies have also supported the prophylactic use of garlic in preventing viral infections in humans by enhancing the immune response. These findings highlight the significant antiviral activity of garlic, making it a potential option for prophylactic use against viral infections (Rouf et al., 2020).

Epidemiological studies indicate that garlic has a substantial impact on reducing deaths attributed to malignant diseases. Consequently, many researchers have extensively studied garlic and its components for their potential antitumor and cytotoxic effects, both in vitro and in laboratory animals. An experimental research demonstrates the effectiveness of A.sativum bulb extracts on both weakly and strongly metastatic cancer cell lines, revealing the mechanisms behind cell death and emphasizing the anticancer properties of the bioactive molecules in Allium sativumL..(Isbilen & Volkan, 2021).

Experimental results showed that administering garlic extract to animals with CCl4-induced liver damage significantly reduced ALT, AST, and ALP enzyme levels, indicating its potent hepatoprotective effects. Garlic extract enhanced antioxidant enzyme activity, countering oxidative stress related to hepatic injury. It increased levels of enzymes like SOD, CAT, and GSH, while reducing lipid peroxidation. These findings highlight garlic extract's hepatoprotective potential, possibly due to its ability to boost antioxidant enzyme activity. (Almatroodi et al., 2020).

Garlic possesses diverse health benefits, including inhibiting bacteria, fungi, and parasites. It also aids in reducing blood pressure, cholesterol, and sugar levels, preventing blood clotting, and safeguarding

the liver. Additionally, it exhibits anticancer properties and enhances the immune system, promoting overall health. Garlic activates the lymphatic system, aiding in waste elimination, and acts as a potent antioxidant, protecting cells from free radical damage (Tesfaye, 2021a)
The preceding information underscores that garlic is a natural gift to humanity. A solitary garlic can serve as a remedy for a wide array of ailments by restraining various bacteria, fungi, harmful viruses and insects. Garlic's cardiovascular, antibiotic, and potential anticancer attributes are widely acknowledged due to substantial scientific evidence(V. K. Singh & Singh, 2008). Based on the comprehensive data discussed above, it becomes increasingly clear that the incorporation of garlic into one's diet is not merely beneficial but also essential for promoting overall health and well-being. The numerous therapeutic properties of garlic, including its antioxidant potential,antidiabetic, antihyperlipidemic,thrombolytic cardioprotective, hepatoprotective, neuroprotectiveand potential anticancer effects, make it a remarkable natural remedy for a variety of health concerns. Embracing garlic as a dietary staple can significantly contribute to improved health outcomes and a strengthened immune system. Therefore, it is advisable to incorporate garlic into your daily nutrition whenever possible, as it represents a simple yet powerful means of supporting and enhancing human health.

CONCLUSION

Numerous scientific investigations have substantiated the multifaceted biological properties of garlic, encompassing antioxidant, anti-inflammatory, cardioprotective, neuroprotective, hepatoprotective, anti-cancer, antibacterial, antifungal, antiviral and other activities. These effects are attributed to the diverse range of bioactive compounds present, including alkaloids, flavonoids, phenolic compounds, and organosulfur compounds like allicin and ajoene. The primary phenolic component found in garlic is β-resorcylic acid, along with others such as pyrogallol and gallic acid. Further research is imperative to gain a comprehensive understanding of the mechanisms underlying garlic's effects. Moreover, the influence of various processing techniques, such as fermentation and heat, on the characteristics and safety of garlic should be more extensively examined. Additionally, additional clinical trials are warranted to validate garlic's potential health benefits for humans, with a careful focus on possible adverse effects and safety considerations.

ACKNOWLEDGMENTS

The authors express their gratitude to the Management of BirTikendrajit University, Canchipur, Imphal West, Manipur, India and KPJ Healthcare University in Nilai, Malaysia, for their unwavering support. The authors also acknowledge the contributions of the authors, editors, and publishers of the articles, journals, and books that were reviewed for the preparation of this review article.

REFERENCES

1. Abdel-Baky, E. S., & Abdel-Rahman, O. N. (2020). Cardioprotective effects of the garlic (Allium sativum) in sodium fluoride-treated rats. *The Journal of Basic and Applied Zoology*, *81*(1), 1–7. https://doi.org/10.1186/s41936-020-0140-0
2. Abubakar, E. M. M. (2009). Efficacy of crude extracts of garlic (Allium sativum Linn.) against nosocomial Escherichia coli, Staphylococcus aureus, Streptococcus pneumoniea and Pseudomonas aeruginosa. *Journal of Medicinal Plants Research*, *3*(4), 179–185.
3. Adineh, H., Harsij, M., Jafaryan, H., & Asadi, M. (2020). The effects of microencapsulated garlic (Allium sativum) extract on growth performance, body composition, immune response and antioxidant status of rainbow trout (Oncorhynchus mykiss) juveniles. *Journal of Applied Animal Research*, *48*(1), 372–378. https://doi.org/10.1080/09712119.2020.1808473
4. Afunwa, R. A., Okonkwo, T. C., Egbuna, R. N., & Ikegbune, C. (2022). Comparative Effects of <i>Allium sativum</i> (Garlic) and <i>Allium porrum</i> (Leek) on Lacerated Wound Isolates. *Open Journal of Internal Medicine*, *12*(04), 184–193. https://doi.org/10.4236/ojim.2022.124020
5. Almatroodi, S. A., Anwar, S., Almatroudi, A., Khan, A. A., Alrumaihi, F., Alsahli, M. A., & Rahmani, A. H. (2020). Hepatoprotective effects of garlic extract against carbon tetrachloride

(CCl4)-induced liver injury via modulation of antioxidant, anti-inflammatory activities and hepatocyte architecture. *Applied Sciences (Switzerland)*, *10*(18). https://doi.org/10.3390/APP10186200

6. Asdaq, S. M. B., Alamri, A. S., Alsanie, W. F., & Alhomrani, M. (2021). Cardioprotective potential of garlic oil and its active constituent, diallyl disulphide, in presence of carvedilol during chronic isoprenaline injection-mediated myocardial necrosis in rats. *Molecules*, *26*(17). https://doi.org/10.3390/molecules26175137
7. Bhanot, A., & Shri, R. (2010). A comparative profile of methanol extracts of Allium cepa and Allium sativum in diabetic neuropathy in mice. *Pharmacognosy Research*, *2*(6), 374–384. https://doi.org/10.4103/0974-8490.75460
8. Bhatwalkar, S. B., Mondal, R., Krishna, S. B. N., Adam, J. K., Govender, P., & Anupam, R. (2021). Antibacterial Properties of Organosulfur Compounds of Garlic (Allium sativum). *Frontiers in Microbiology*, *12*(July), 1–20. https://doi.org/10.3389/fmicb.2021.613077
9. Choudhary, R. (2008). Benificial Effect of Allium Sativum and Allium Tuberosum on Experimental Hyperlipidemia and. *Pak J Physiol*, *4*(2), 7–9.
10. Donma, M. M., & Donma, O. (2020). The effects of allium sativum on immunity within the scope of COVID-19 infection. *Medical Hypotheses*, *144*(June), 109934. https://doi.org/10.1016/j.mehy.2020.109934
11. Eja, M. E., Asikong, B. E., Abriba, C., Arikpo, G. E., Anwan, E. E., & Enyi-ldoh, K. H. (2007). A comparative assessment of the antimicrobial effects of garlic (Allium sativum) and antibiotics on diarrheagenic organisms. *Southeast Asian Journal of Tropical Medicine and Public Health*, *38*(2), 343–348.
12. Fesseha, H., & Goa, E. (2019). Therapeutic Value of Garlic (Allium sativum): A Review. *Advances in Food Technology and Nutrition Sciences – Open Journal*, *5*(3), 107–117. https://doi.org/10.17140/aftnsoj-5-162
13. Hegazy, E. M., Sabry, A., & Khalil, W. K. B. (2022). Neuroprotective effects of onion and garlic root extracts against Alzheimer's disease in rats: antimicrobial, histopathological, and molecular studies. *Biotechnologia*, *103*(2), 153–167. https://doi.org/10.5114/bta.2022.116210
14. Iqbal, Z., Nadeem, Q. K., Khan, M. N., Akhtar, M. S., & Waraich, F. N. (2001). In vitro anthelmintic activity of Allium sativum, Zingiber officinale, Cucurbita mexicana and Ficus religiosa. *International Journal of Agriculture and Biology*, *3*(4), 454–457.
15. Isbilen, O., & Volkan, E. (2021). Anticancer Activities of Allium sativum L. Against MCF-7 and MDA-MB-231 Breast Cancer Cell Lines Mediated by Caspase-3 and Caspase-9. *Cyprus Journal of Medical Sciences*, *5*(4), 305–312. https://doi.org/10.5152/cjms.2020.1848
16. Islamic, I. (2012). 31-Rahman. *International Food Research Journal*, *19*(2), 589–591.
17. Khorshed Alam, M., Obydul Hoq, M., & Shahab Uddin, M. (2016). Medicinal plant Allium sativum = A Review. *Journal of Medicinal Plants Studies*, *4*(6), 72–79.
18. Kiprop, S., & Muthangya, M. (n.d.). *Phytochemical Screening and Antimicrobial Properties of Allium sativum Against Lactobacillus*. *4531*, 172–180.
19. Kovarovič, J., Bystrická, J., Vollmannová, A., Tóth, T., & Brindza, J. (2019). Biologically valuable substances in garlic (Allium sativum l.)-a review. *Journal of Central European Agriculture*, *20*(1), 292–304. https://doi.org/10.5513/JCEA01/20.1.2304
20. Kuzgun, N. K. (2019). Effect of Garlic (Allium sativum L.) essential oils on Oncorhynchus mykiss fillets during storage. *Progress in Nutrition*, *21*(3), 709–714. https://doi.org/10.23751/pn.v21i3.8694
21. Lawal, B., Shittu, O. K., Oibiokpa, F. I., Mohammed, H., Umar, S. I., & Haruna, G. M. (2016). Antimicrobial evaluation, acute and sub-acute toxicity studies of Allium sativum. *Journal of Acute Disease*, *5*(4), 296–301. https://doi.org/10.1016/j.joad.2016.05.002
22. Lemar, K. M., Passa, O., Aon, M. A., Cortassa, S., Müller, C. T., Plummer, S., O'Rourke, B., & Lloyd, D. (2005). Allyl alcohol and garlic (Allium sativum) extract produce oxidative stress in Candida albicans. *Microbiology*, *151*(10), 3257–3265. https://doi.org/10.1099/mic.0.28095-0
23. Maisaroh, S., Zahro, C., Puspitosari, D. R., Wahdi, A., & Pratiwi, T. F. (2020). Effective

Consumption of Garlic (Allium Sativum Linn) on Decreasing Blood Cholesterol Levels. *IOP Conference Series: Earth and Environmental Science*, *519*(1). https://doi.org/10.1088/1755-1315/519/1/012004

24. Meriga, B., Mopuri, R., & MuraliKrishna, T. (2012). Insecticidal, antimicrobial and antioxidant activities of bulb extracts of Allium sativum. *Asian Pacific Journal of Tropical Medicine*, *5*(5), 391–395. https://doi.org/10.1016/S1995-7645(12)60065-0
25. Metwally, M. A. A. (2009). Effects of garlic (Allium sativum) on some antioxidant activities in tilapia nilotica (Oreochromis niloticus). *World Journal of Fish and Marine Sciences*, *1*(1), 56–64.
26. Mona, M. M., Ali, H. F., & Rizk, M. Z. (2011). Efeitos Terapêuticos Do Allium Sativum E Allium Cepa Na Infecção Experimental Pelo Schistosoma Mansoni. *Revista Do Instituto de Medicina Tropical de Sao Paulo*, *53*(3), 155–163. https://doi.org/10.1590/S0036-46652011000300007
27. Morales-González, J. A., Madrigal-Bujaidar, E., Sánchez-Gutiérrez, M., Izquierdo-Vega, J. A., Carmen Valadez-Vega, M. Del, Álvarez-González, I., Morales-González, Á., & Madrigal-Santillán, E. (2019). Garlic (Allium sativum L.): A brief review of its antigenotoxic effects. *Foods*, *8*(8), 1–17. https://doi.org/10.3390/foods8080343
28. Nazir, I., & Chauhan, R. S. (2019). Qualitative phytochemical analysis of Allium sativum (Garlic) and Curcuma longa (Turmeric). *~ 545 ~ Journal of Entomology and Zoology Studies*, *7*(1), 545–547.
29. Nuswantoro, A., & Berlianti, J. N. (2022). Potential of Garlic Filtrate as An Alternative Anticoagulant for Whole Blood Samples. *Indonesian Journal of Medical Laboratory Science and Technology*, *4*(2), 111–119. https://doi.org/10.33086/ijmlst.v4i2.2683
30. Onyeagba, R. A., Ugbogu, O. C., Okeke, C. U., & Iroakasi, O. (2004). Studies on the antimicrobial effects of garlic (Allium sativum Linn), ginger (Zingiber officinale Roscoe) and lime (Citrus aurantifolia Linn). *African Journal of Biotechnology*, *3*(10), 552–554. https://doi.org/10.5897/AJB2004.000-2108
31. P. Saravanan, V. Ramya, H. Sridhar, V. Balamurugan, S. U. (2010). antibacterial activity of Allium sativum L. on Pathogenic Bacterial Strains. *Global Veterinaria*, *4*(5), 519–522.
32. Peng, Q., Buz'Zard, A. R., & Lau, B. H. S. (2002). Neuroprotective effect of garlic compounds in amyloid-β peptide-induced apoptosis in vitro. *Medical Science Monitor*, *8*(8), 328–338.
33. Rempel, C. (2021). *Recent Scientific Production of Garlic (Allium sativum L .) confirms important therapeutic properties A recente produção científica de alho (Allium sativum L .) confirma importantes propriedades terapêuticas*. 51030–51055. https://doi.org/10.34117/bjdv7n5-481
34. Rouf, R., Uddin, S. J., Sarker, D. K., Islam, M. T., Ali, E. S., Shilpi, J. A., Nahar, L., Tiralongo, E., & Sarker, S. D. (2020). Antiviral potential of garlic (Allium sativum) and its organosulfur compounds: A systematic update of pre-clinical and clinical data. *Trends in Food Science and Technology*, *104*(August), 219–234. https://doi.org/10.1016/j.tifs.2020.08.006
35. Samson, E. (2012). Haematological and Hepatotoxic Potential of Onion (Allium cepa) and Garlic (Allium sativum) Extracts in Rats. *European Journal of Medicinal Plants*, *2*(4), 290–307. https://doi.org/10.9734/ejmp/2012/1517
36. Sasi, M., Kumar, S., Kumar, M., Thapa, S., Prajapati, U., Tak, Y., Changan, S., Saurabh, V., Kumari, S., Kumar, A., Hasan, M., Chandran, D., Radha, Bangar, S. P., Dhumal, S., Senapathy, M., Thiyagarajan, A., Alhariri, A., Dey, A., … Mekhemar, M. (2021). Garlic (Allium sativum L.) bioactives and its role in alleviating oral pathologies. *Antioxidants*, *10*(11). https://doi.org/10.3390/antiox10111847
37. Satyal, P., Craft, J. D., Dosoky, N. S., & Setzer, W. N. (2017). The chemical compositions of the volatile oils of garlic (Allium sativum) and wild garlic (allium vineale). *Foods*, *6*(8), 1–10. https://doi.org/10.3390/foods6080063
38. Sh, D., Seidgar, M., Nekuiefard, A., Valipour, A. R., Sharifian, M., & Hafezieh, M. (2019). Oral administration of garlic powder (Allium sativum) on growth performance and survival rate of

Carassius auratus fingerlings. *Iranian Journal of Fisheries Sciences*, *18*(1), 71–82. https://doi.org/10.22092/ijfs.2018.117478
39. Shang, A., Cao, S. Y., Xu, X. Y., Gan, R. Y., Tang, G. Y., Corke, H., Mavumengwana, V., & Li, H. Bin. (2019). Bioactive compounds and biological functions of garlic (allium sativum L.). *Foods*, *8*(7), 1–31. https://doi.org/10.3390/foods8070246
40. Sheik, R., & Ramamurthy, J. (2020). Antimicrobial effect of garlic on oral microbes - An in vitro study. *Drug Invention Today*, *14*(3), 197–201.
41. Shooriabi, M. (2021). Effects of Allium sativum (Garlic) and Its Derivatives on Oral Diseases: A Narrative Review. *J Res Dent Maxillofac Sci*, *6*(1), 36–44. http://jrdms.dentaliau.ac.ir/article-1-295-fa.html
42. Singh, V. K., & Singh, D. K. (2008). *ARBS Annual Review of Biomedical Sciences Pharmacological Effects of Garlic (Allium sativum L .)*. 6–26.
43. Singh, V., & Kumar, R. (2017). Study of Phytochemical Analysis and Antioxidant Activity of Allium sativum of Bundelkhand Region. *International Journal of Life-Sciences Scientific Research*, *3*(6), 1451–1458. https://doi.org/10.21276/ijlssr.2017.3.6.4
44. Stanaćev, V., Glamočić, D., Milošević, N., Puvača, N., Stanaćev, V., & Plavša, N. (2011). Effect of garlic (allium sativum l.) in fattening chicks nutrition. *African Journal of Agricultural Research*, *6*(4), 943–948.
45. Strika, I., Bašić, A., & Halilović, N. (2017). Bulletin of the Chemists and Technologists of Bosnia and Herzegovina Antimicrobial effects of garlic (Allium sativum L .). *Organic Scientist*, *47*(December 2016), 17–20.
46. Suleiman, E., & Abdallah, W. (2014). In vitro Activity of Garlic (Allium sativum) on Some Pathogenic Fungi. *European Journal of Medicinal Plants*, *4*(10), 1240–1250. https://doi.org/10.9734/ejmp/2014/10132
47. Szychowski, K. A., Rybczyńska-Tkaczyk, K., Gaweł-Bęben, K., Aświeca, M., Kara, M., Jakubczyk, A., Matysiak, M., Binduga, U. E., & Gmiński, J. (2018). Characterization of Active Compounds of Different Garlic (Allium sativum l.) Cultivars. *Polish Journal of Food and Nutrition Sciences*, *68*(1), 73–81. https://doi.org/10.1515/pjfns-2017-0005
48. Tanrıkulu, C. Ş., Tanrikulu, Y., Kılınç, F., Bahadır, B., Can, M., & Köktürk, F. (2017). Deneysel korozif özefagus yanıklarında sarımsak yağının (Allium Sativum) yararlı etkileri. *Ulusal Travma ve Acil Cerrahi Dergisi*, *23*(3), 181–187. https://doi.org/10.5505/tjtes.2016.64509
49. Tesfaye, A. (2021a). Revealing the Therapeutic Uses of Garlic (Allium sativum) and Its. *The Scientific World Journal*, *2021*, 1–7.
50. Tesfaye, A. (2021b). Revealing the Therapeutic Uses of Garlic (Allium sativum) and Its Potential for Drug Discovery. *Scientific World Journal*, *2021*(10). https://doi.org/10.1155/2021/8817288
51. Țigu, A. B., Moldovan, C. S., Toma, V. A., Farcaș, A. D., Moț, A. C., Jurj, A., Fischer-Fodor, E., Mircea, C., & Pârvu, M. (2021). Phytochemical analysis and in vitro effects of allium fistulosum l. And allium sativum l. extracts on human normal and tumor cell lines: A comparative study. *Molecules*, *26*(3), 1–19. https://doi.org/10.3390/molecules26030574
52. Tsai, J. C., Chen, Y. A., Wu, J. T., Cheng, K. C., Lai, P. S., Liu, K. F., Lin, Y. K., Huang, Y. T., & Hsieh, C. W. (2019). Extracts from fermented black garlic exhibit a hepatoprotective effect on acute hepatic injury. *Molecules*, *24*(6), 1–13. https://doi.org/10.3390/molecules24061112
53. Ullah, S., Khan, F. U., Zaman, L., Abbas, S., Shah, M. S., Rehman, J. U., Mangi, A. H., Khan, A. R., Khan, B., Rani, S. S., Gul, S., & Khattak, A. (2022). The Assessment of the Allium sativum and Tamarix aphylla Comparative and Combined Antioxidant Potential. *Journal of Pharmaceutical Research International*, *34*, 7–12. https://doi.org/10.9734/jpri/2022/v34i45b36359
54. VISWANATHAN, V., PHADATARE, A. G., & MUKNE, A. (2014). Antimycrobacterial and Anti bacterial Activity of sativum bulbs. *Indian Journal of Pharmaceutical Sciences*, *June*, 256–261.
55. Wang, D., Feng, Y., Liu, J., Yan, J., Wang, M., & Changlong, J. S. (2010). *Black Garlic (Allium sativum) Extracts Enhance the Immune System*.

56. Yasin, G., Jasim, S. A., Mahmudiono, T., Al-Shawi, S. G., Shichiyakh, R. A., Shoukat, S., Kadhim, A. J., Iswanto, A. H., Saleh, M. M., & Fenjan, M. (2022). Investigating the effect of garlic (Allium sativum) essential oil on foodborne pathogenic microorganisms. *Food Science and Technology (Brazil)*, *42*, 1–6. https://doi.org/10.1590/FST.03822