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A REVIEW ON CHEMICAL CONSTITUENTS AND BIOLOGICAL ACTIVITIES OF GARLIC (ALLIUM SATIVUM)

[1]Pushpraj Singh and [2]Manish Sachan

1- Assistant Professor, Department of Chemistry, Govt. Girls Degree College, Chhibramau, Kannauj-209721, Uttar Pradesh, India

2- Assistant Professor, Department of Zoology, Govt. Girls Degree College, Chhibramau, Kannauj-209721, Uttar Pradesh, India

Abstract

Medicinal plants have been used from ancient times for human healthcare as in the form of traditional medicines, spices, and other food components. Garlic (Allium sativum) is a widely consumed spice in the world. Garlic is an excellent natural source of bioactive sulfur-containing compounds and has promising applications in the development of functional foods or nutraceuticals for the prevention and management of certain diseases. It has been reported to possess several biological properties including anticarcinogenic, antioxidant, antidiabetic, renal protective, anti-atherosclerotic, antibacterial, antifungal, and antihypertensive activities in traditional medicines. A. sativum is rich in several sulfur-containing phytoconstituents such as alliin, allicin, ajoenes, vinyldithiins, and flavonoids such as quercetin. Extracts and isolated compounds of A. sativum have been evaluated for various biological activities including antibacterial, antiviral, antifungal, antiprotozoal, antioxidant, anti-inflammatory, and anticancer activities among others. In this review, the main bioactive compounds and important biological functions of garlic are summarized.

Keywords: Garlic, Allium sativum, phytoconstituents, phytochemicals, pharmacological activities, pharmacokinetics, allicin, organic sulfides, antioxidant, anticancer, cardiovascular protection.

1. Introduction

Garlic (Allium sativum) is a common spice with many health benefits, mainly due to its diverse bioactive compounds, such as organic sulfides, saponins, phenolic compounds, and polysaccharides. Garlic is commonly consumed and has a long history of being utilized as a traditional medicine in India. In recent decades, numerous studies have demonstrated the remarkable biological functions of garlic, including antioxidant, cardiovascular protective, anticancer, anti-inflammatory, immunomodulatory, anti-diabetic, anti-obesity, and antibacterial properties. In order to highlight the significance of garlic in human health, we searched high-quality studies from the last five years from the Web of Science Core Collection and reviewed the main bioactive compounds and biological functions of garlic, with special attention paid to the relevant

mechanisms of actions. We hope that this review paper will attract more interest in garlic and provide updated scientific evidence for the better utilization of garlic in human health and disease management.

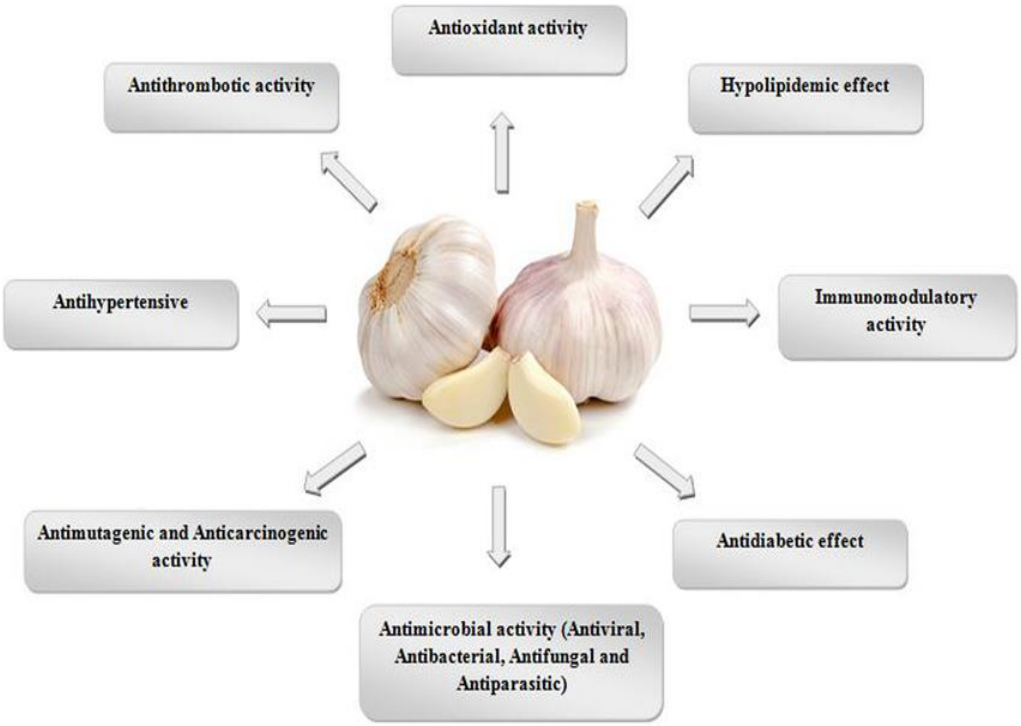
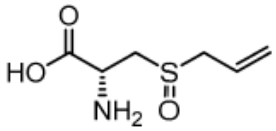
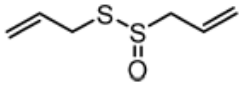
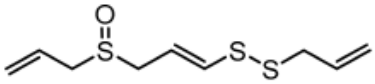
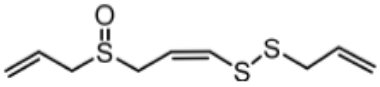
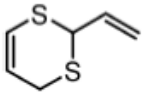
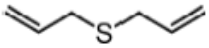
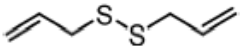
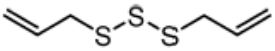
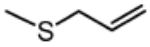


Figure 1: Biological Activities of Garlic (Allium sativum)

2. Bioactive Compounds of Garlic

Garlic has a variety of bioactive compounds, including organosulfur compounds, saponins, phenolic compounds, and polysaccharides. The major active components of garlic (Table 1) are its organosulfur compounds, such as diallyl thiosulfonate (allicin), diallyl sulfide (DAS), diallyl disulfide (DADS), diallyl trisulfide (DATS), E/Z-ajoene, S-allyl-cysteine (SAC), and S-allyl-cysteine sulfoxide (alliin). In general, organosulfur compounds in raw garlic have higher digestibility than those in cooked garlic. In addition, saponins were found to be more stable in the cooking process. The total amount of saponin in purple garlic was almost 40 times higher than that in white garlic, and several saponin compounds were only found to exist in purple garlic, such as desgalactotigonin-rhamnose, proto-desgalactotigonin, proto-desgalactotigonin-rhamnose, voghieroside D1, sativoside B1-rhamnose, and sativoside R1. Moreover, garlic contained more than 20 phenolic compounds, with higher contents than many common vegetables. The main phenolic compound was β-resorcylic acid, followed by pyrogallol, gallic acid, rutin, protocatechuic acid, as well as quercetin.

Table 1. List and structures of some of the sulfur-containing compounds isolated from *Allium sativum*.

Compounds	Molecular formula	Structure
Alliin	$C_6H_{11}NO_3S$	
Allicin	$C_6H_{10}OS_2$	
E-Ajoene	$C_9H_{14}OS_3$	
Z-Ajoene	$C_9H_{14}OS_3$	
2-Vinyl-4H-1,3-dithiin	$C_6H_8S_2$	
Diallyl sulfide (DAS)	$C_6H_{10}S$	
Diallyl disulfide (DADS)	$C_6H_{10}S_2$	
Diallyl trisulfide (DATS)	$C_6H_{10}S_3$	
Allyl methyl sulfide (AMS)	C_4H_8S	

3. Biological Activities of Garlic

3.1. Antioxidant Activity

The antioxidant activities of natural products have been widely evaluated, such as fruits, vegetables, mushrooms, cereal, flowers, and wild fruits. Accumulating studies have found that garlic has strong antioxidant properties. A study evaluated the antioxidant capacities of both raw and cooked garlic, and found that the raw garlic exhibited stronger antioxidant activity (by 1,1-diphenyl-2-picrilhydrazyl (DPPH) radical scavenging assay, 2,2'-Azino-bis(3-ethyl benzothiazoline-6-sulfonic acid) (ABTS) radical scavenging assay, and ferric ion reducing antioxidant power (FRAP) assay). Stir-fried garlic was also shown to have stronger antioxidant capacities (by β-carotene bleaching), indicating that the processing could affect the antioxidant property of garlic. In another study, the results of DPPH and oxygen radical absorption capacity (ORAC) assays showed that the ethanolic extract of garlic sprouts exhibited stronger antioxidant activities than the ethanolic extract of raw garlic. In addition, the antioxidant properties of aged garlic were found to be higher than fresh garlic by DPPH, ABTS, FRAP, H_2O_2 scavenging, and Fe^{2+} chelating assays.

3.2. Anti-Inflammatory Activity

Garlic and its bioactive compounds have also been shown to exhibit anti-inflammatory properties. In a study, the ethyl linoleate in garlic reduced the production of nitric oxide (NO) and prostaglandin E-2 by down-regulating the expression of inducible NO synthase (iNOS) and cyclooxygenase-2 (COX2) in lipopolysaccharide-stimulated RAW 264.7 macrophages. Another study revealed that the garlic 14-kDa protein inhibited the inflammatory mediators including NO, TNF-α, and interleukin (IL) -1β by inhibiting the transcription factor nuclear factor-kappa B (NF-κB) signaling pathway in lipopolysaccharide-stimulated J774A.1 macrophages. In addition, AGE inhibited inflammation in apolipoprotein E-knockout mice. Garlic has great potential to treat inflammatory diseases, such as arthritis, in humans, because of its low or absent toxicity.

3.3. Antimicrobial Activity

Garlic has a broad spectrum of antibacterial and antifungal properties. Garlic oil also had antibacterial activities and could restrict the growth of Staphylococcus aureus, Escherichia coli, and Bacillus subtilis. It was found that garlic oil inhibited the fungus Penicillium funiculosum, probably by penetrating into cells and organelles, destroying the cell structure, and inducing the leakage of cytoplasm and macromolecules. Additionally, garlic oil was found to disrupt the normal metabolism of Candida albicans, which is associated with the induction of key genes involved in oxidative phosphorylation, the cell cycle, and protein processing in the endoplasmic reticulum. Furthermore, in a clinical trial, the treatment of raw garlic inhibited Helicobacter pylori in the stomach of patients with H. pylori infection.

3.4. Modulating Immune System

Garlic contains many bioactive compounds that are beneficial for the immune system. Garlic polysaccharides have an immunomodulatory effect and regulate the expressions of IL-6, IL-10, TNF-α, and interferon-γ in RAW 264.7 macrophages. Compared with black garlic, polysaccharides in fresh garlic exhibit a more potent activity in immunomodulation.

3.5. Cardiovascular Protection

Recently, the numbers of deaths from cardiovascular diseases have significantly risen. There has been a growing interest in natural products to protect the cardiovascular system, and garlic is one of the most promising candidates. It has been demonstrated that the intake of garlic powder can effectively reduce blood pressure, total cholesterol, low-density lipoprotein cholesterol, and other risk factors related to cardiovascular diseases. Garlic has been shown to increase Na+/K+-ATPase protein levels and reduce cardiac hypertrophy and remodeling induced by isoproterenol in rats.

3.6. Anticancer Activity

Cancer is acknowledged to be a primary cause of death in the world, and various natural products like berries, cruciferous vegetables, tomatoes, and ginger have been demonstrated to possess anticancer properties. Recent studies have also shown that garlic and its active constituents can protect against diverse cancers, such as colorectal, lung, gastric, and bladder cancers.

3.7. Digestive System Protection

Garlic has been reported to have therapeutic efficacy against gastric tissue injury. A study showed that black garlic extract can stimulate gastrointestinal peristalsis, promote gastrointestinal emptying, and facilitate defecation. The water fraction of black garlic had a better effect on improving gastrointestinal functions compared with the n-butanol fraction and ethyl acetate fraction in the small intestine in vitro. Additionally, the treatment by garlic and cabbage extract reduced the length of gastric ulcers, total gastric acid, gastric juice volume, total bacteria count, and changes in histopathology. The bioactive compounds in garlic were also crucial in the protection of the digestive system. In general, garlic and its bioactive compounds can improve gastrointestinal functions and alleviate colitis, gastric ulcers, and other gastrointestinal diseases by reducing oxidative stress, inhibiting inflammation, and decreasing Helicobacter pylori.

3.8. Anti-Diabetic Activity

Garlic has been shown to reduce pancreatic cell injury, oxidative stress, and pathological changes in streptomycin-induced type 1 diabetic rats. In addition, garlic had a protective effect on diabetic retinopathy in diabetic rats. The weight, blood glucose, and morphological changes of retinal tissue in the group treated with garlic improved after 7 weeks of gastric gavage of raw garlic extract in rats.

3.9. Neuroprotection

Both in vivo and in vitro experiments showed that garlic has significant neuroprotective properties and mainly acts on the hippocampus. Organic sulfur compounds were shown to play a major role in neuroprotection.

3.10. Renal Protection

Garlic was shown to effectively alleviate nephrotoxicity. The aqueous extract of garlic was shown to reduce the oxidative stress in the kidneys of diabetic rats. In addition, the aqueous extract of garlic improved the renal plasma biochemical factors induced by alloxan in Wistar rats. Moreover, DATS was reported to activate the Nrf2-ARE pathway, protecting the kidney from oxidative stress injury induced by arsenic in rats.

4. Conclusion

Garlic is a widely consumed spice with a characteristic odor. It contains many bioactive components, such as organic sulfides, saponins, phenolic compounds, and polysaccharides. The organic sulfides, such as allicin, alliin, diallyl sulfide, diallyl disulfide, diallyl trisulfide, ajoene, and S-allyl-cysteine, are major bioactive components in garlic. Garlic and its bioactive components show many biological functions, such as antioxidant, anti-inflammatory, immunomodulatory, cardiovascular protective, anticancer, hepatoprotective, digestive system protective, anti-diabetic, anti-obesity, neuroprotective, renal protective, antibacterial, and antifungal activities. Generally, garlic is non-toxic or has low toxicity. Therefore, garlic and its bioactive compounds are promising as functional foods or nutraceuticals for the prevention and treatment of different diseases. In the future, more biological functions of garlic should be evaluated, and the relative compounds of garlic need to be separated and identified. More investigations should be conducted to deeply illustrate garlic’s mechanisms of action. In addition, the effects of the processing, such as fermentation and heat, on garlic should be further studied because they could impact the biological functions and safety of garlic. Furthermore, more clinic trials should be carried out to confirm the health benefits of garlic on humans, and special attention should be paid to the side effects/safety of garlic.

5. Acknowledgement

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6. Conflicts of Interest

The authors declare no conflict of interest.

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