GSC Biological and Pharmaceutical Sciences
eISSN: 2581-3250 CODEN (USA): GBPSC2
Cross Ref DOI: 10.30574/gscbps
Journal homepage: https://gsconlinepress.com/journals/gscbps/

(REVIEW ARTICLE)

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Garlic (*Allium sativum*): An in-depth review focusing on its potent antiparasitic activity

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GSC Biological and Pharmaceutical Sciences, 2024, 28(03), 007–026

Publication history: Received on 20 July 2024; revised on 30 August 2024; accepted on 01 September 2024

Article DOI: https://doi.org/10.30574/gscbps.2024.28.3.0306

Abstract

Garlic (*Allium sativum*) is widely recognized not just for its culinary properties but also for its impressive broad spectrum of health benefits. This review delves into both the culinary and therapeutic usages of garlic, with a particular focus on its remarkable antiparasitic characteristics. In addition, the current review study highlights garlic's effectiveness against various parasitic infections, due to its rich content of bioactive compounds such as allicin, ajoene, diallyl sulfides and many others. These compounds have shown substantial antiparasitic activity in both *in vitro* and *in vivo* studies. Moreover, the review summarizes findings from numerous studies that demonstrated garlic's effectiveness in treating a range of parasitic diseases, including malaria, giardiasis, leishmaniasis, schistosomiasis, and others. Besides, it discusses the mechanisms through which garlic's bioactive compounds exert their antiparasitic effects, such as interfering with parasite metabolism, blocking enzyme functions, and boosting the host's immune response. Additionally, the review considers garlic's potential as a supplementary or alternative treatment for conventional antiparasitic medications, particularly in regions where drug resistance is a concern or access to standard therapies is restricted. In summary, garlic emerges as a highly promising natural remedy with notable antiparasitic properties. To fully harness its potential, ongoing research and clinical trials are crucial. These efforts will help refine its therapeutic applications and establish effective treatment protocols for combating parasitic infections.

Keywords: Garlic; *Allium sativum*; Parasites; Infection; Allicin; Anti-parasitic

1. Introduction

For centuries, long prior the advent of chemical medicines, humans have turned to medicinal plants for healing. There was a deep-seated belief that these plants were created unambiguously to provide both nourishment and medical treatment for people. This belief remains strong in numerous developing countries today, where residents continue to rely on these plants for treatment. In these regions, traditional medicine, with medicinal plants at its core, remains the main source of healthcare (1). It's fascinating to recognize that using herbal remedies for preventing and treating illnesses is a tradition that has lasted through centuries. Many of today's medications actually trace their origins back to the study of plants. For instance, medicines like aspirin, atropine, codeine, ephedrine, digoxin, L-dopa, and morphine were originally discovered through deep research into medicinal plants and the wisdom of indigenous cultures. Besides being generally more cost-effective than synthetic drugs, these herbal treatments often come with fewer side effects (2, 3). Medicinal plants are those recognized for their ability to relieve or cure illnesses, and they have been used as remedies across different cultures for generations. They play a crucial role in both traditional and contemporary

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medicine, with many modern pharmaceuticals being based on plant-derived compounds. Around 50,000 medicinal plants are used worldwide, with a significant number having well-documented therapeutic properties (4, 5). Furthermore, the practice of using medicinal plants stretches back thousands of years, deeply rooted in ancient history. Historic manuscripts like the Ebers Papyrus and the Chinese Pen T'Sao offer a window into this enduring tradition, meticulously cataloging the healing properties of a wide array of plants. These ancient texts not only record the use of numerous plant species but also underline a timeless bond between humans and the natural world. Many of the plants mentioned in these revered documents continue to be integral to modern herbal medicine, showcasing the remarkable continuity of this age-old practice (6, 7). Research highlights the vital role that indigenous knowledge about medicinal plants plays in creating new treatments. A particular study focusing on the semi-nomadic Goji people of Ethiopia showcased the rich cultural significance and variety of medicinal plants they utilize for healing. The study underscored the urgent need to safeguard this knowledge, as it is traditionally passed down through generations but is increasingly threatened by modern advancements (8). Across the ages, medicinal plants have developed and flourished, leading to a wide array of uses. Garlic (*Allium sativum*) is a notable example, famed for its vast health advantages. This is largely due to allicin, a powerful compound widely recognized for its therapeutic effects in several cultures and healing traditions. (9, 10). Moreover, garlic possesses potent antimicrobial properties, making it effective against a wide range of bacteria, viruses, fungi, and even parasites. The active compound allicin plays a crucial role in these effects, which is why garlic has been historically used as a natural remedy for combating microbial infections (11, 12). Garlic's reputation as a heart-healthy superfood is well-earned. It has been proven to effectively lower blood pressure, decrease levels of LDL cholesterol (the so-called "bad" cholesterol), and prevent platelet aggregation, which reduces the risk of heart attacks and strokes. For individuals with cardiovascular conditions, regularly incorporating garlic into their diet can lead to substantial health improvements, solidifying its place as a cornerstone of heart disease prevention (13, 14). In addition, garlic boasts a range of vital health benefits, including immune system enhancement (15), anti-cancer properties (16), anti-inflammatory effects (17), and powerful antioxidant activity (18). These significant advantages underscore the exceptional value of garlic as a medicinal plant, cementing its status as a true natural remedy.

2. Historical background and Scientific classification

Garlic (*Allium sativum*) is a bulbous flowering plant from the Allium genus, sharing close ties with onions, shallots, leeks, chives, Welsh onions, and Chinese onions. Originating from Central Asia, South Asia, and northeastern Iran, garlic has a storied history as a cherished seasoning in kitchens around the world for thousands of years (19, 20). In addition, *Allium sativum* is divided into two main subspecies, which further branch into ten major groups and hundreds of distinct varieties or cultivars. The first subspecies, *A. sativum* var. ophioscorodon (Link) Döll, known as Ophioscorodon or hard neck garlic, includes types such as porcelain garlic, rocambole garlic, and purple stripe garlic. The second subspecies, *A. sativum* var. sativum, commonly called soft neck garlic, features varieties like artichoke garlic, silver skin garlic, and creole garlic. This diversity underscores garlic's versatility and its enduring role in global cuisine (20, 21, 22, 23). On the other hand, Garlic is thought to have a rich history spanning thousands of years, with some sources suggesting it has been cultivated for over 5,000 years. Ancient records reveal its use by the Sumerians around 2600-2100 BC, who valued garlic for its medicinal properties. The Egyptians later adopted garlic, elevating it to a sacred status. It was believed that the laborers who constructed the pyramids consumed garlic to boost their strength and endurance. Archaeological findings even indicate that clay models of garlic bulbs were placed in tombs, possibly as offerings or provisions for the afterlife, highlighting its cultural and spiritual significance (24, 25). Besides, Garlic eventually found its way to ancient Greece and Rome, where it became a staple for both culinary and medicinal purposes. Greek athletes consumed garlic to boost their performance, while Romans valued it as a source of strength. Beyond its nutritional benefits, garlic was also believed to possess protective qualities, thought to ward off diseases and pests, further embedding it into the daily lives and practices of these ancient civilizations (24, 26, 27). Furthermore, Garlic, scientifically known as Allium sativum, is a bulbous flowering plant belonging to the family Alliaceae. Table (1) below is the illustration of the scientific classification of Garlic.

Table 1 The scientific classification of *Allium sativum L*. (cultivated garlic). (28).

Rank	Scientific Name and Common Name
Kingdom	*Plantae* - Plants
Subkingdom	*Tracheobionta* - Vascular plants
Superdivision	*Spermatophyta* - Seed plants
Division	*Magnoliophyta* - Flowering plants

Class	*Liliopsida* - Monocotyledons
Subclass	*Liliidae*
Order	*Liliales*
Family	*Liliaceae Juss.* - Lily family
Genus	*Allium L.* - onion
Species	*Allium sativum L. - cultivated garlic*

3. Botanical description

Garlic is a notable perennial herb valued for its medicinal properties. Typically growing to about three feet, or nearly a meter, in height from its bulb, garlic stands out with its potent aroma and unique flavor. Each bulb contains between ten and twenty cloves, each encased in a thin, papery skin. In cooking and traditional medicine, it is the cloves that are primarily utilized. Interestingly, the cloves closest to the center of the bulb tend to be symmetrical, whereas those on the outer layers can be irregular in shape (29, 30, 31). In addition, it boasts long, sleek leaves that stretch up to 60 cm (24 inches) in length and about 1.25 to 2.5 cm (0.5 to 1 inch) in width. Arranged in a rosette formation, these leaves end at a sharp tip and often reveal a distinctive ridge on their undersides. Each variety of garlic presents its own unique leaf shape, adding to the plant's diverse visual appeal (31, 32). Furthermore, the garlic plant's flowering stem, known as the scape, stands tall and straight, reaching up to 1 meter (3 feet) in height. From July to September, it showcases a globe-like cluster of delicate flowers that range in color from greenish-white to pink. Each flower features six tepals. The shape and arrangement of the scape can differ widely depending on the plant's genetic variety, with research highlighting variations in both flower structure and arrangement (30,33).

4. Chemical constituents

Garlic (*Allium sativum*) is rich in a diverse array of chemical compounds that play a crucial role in its distinctive flavor, aroma, and numerous health benefits. Among its most significant constituents are organosulfur compounds, which include a variety of key substances such as allicin, diallyl disulfide, diallyl trisulfide, and S-allylcysteine. Allicin, which is released when garlic is crushed or chopped, stands out for its powerful antimicrobial and antioxidant properties, making it a focal point of garlic's therapeutic effects (34, 35, 36). Beyond its organosulfur compounds, garlic is packed with a range of other beneficial phytochemicals like flavonoids and phenolic compounds. Notable among these are quercetin, gallic acid, and β-resorcylic acid, all celebrated for their antioxidant properties and potential health benefits. Additionally, Garlic is packed with saponins and polysaccharides, which not only boost its nutritional value but also enhance its overall health benefits (35). Moreover. The chemical makeup of garlic can differ depending on factors like the variety of garlic, its growing environment, and how it's processed. Research indicates that both pre- and post-harvest conditions can alter the levels of bioactive compounds, impacting their effectiveness and health benefits. Ultimately, the varied chemical components of garlic are crucial to its role as a functional food and its use in both traditional and contemporary medicine (37, 38). Table 2, below illustrates the key chemical components of garlic,

Table 2 The most significant chemical constituents of garlic**.**

Component	**Comments**	**Ref**
Allicin	Organosulfur Compound The main bioactive compound in garlic Responsible for its characteristic odor and pungent taste	39, 40, 41
Diallyl sulfide, Diallyl disulfide, Diallyl trisulfide, S-allyl-cysteine	Sulfur Compounds Responsible for many of garlic's therapeutic effects	35, 42
Alliin and Alliinase	Alliin is a sulfur-containing amino acid that is the precursor of allicin Alliinase is an enzyme that converts Alliin into allicin when garlic is crushed This conversion is crucial for garlic's medicinal properties.	35, 43, 44

Flavonoids (e.g., quercetin):	Contribute to its antioxidant activity Significant in inhibiting oxidative stress Mitigate the risk of chronic diseases Reduce blood pressure and improve cardiovascular health	35, 45, 46
Saponins	Group of naturally occurring glycosides A hydrophilic (water-soluble) sugar part and a hydrophobic (fat-soluble) aglycone part Antioxidant Properties, Cardiovascular Benefits, Antimicrobial Activity and Immune Modulation	35, 47, 48
Phenolic compounds	Contribute significantly to its health benefits and biological activities. Antioxidant properties β-Resorcylic Acid: This is one of the predominant phenolic compounds found in garlic Quercetin: This flavonoid is a well-known antioxidant	35, 49, 50
Polysaccharides	Belong to the neokestose-based fructans family Characterized by an inulin-type structure Soluble in water and easily digestible Health benefits, including antioxidant, immune-modulating, promoting gut health and hypolipidemic effects.	35, 51, 52
Vitamins, minerals, proteins, and enzymes	Present in smaller amounts Significant for garlic's overall nutritional profile	53, 54

5. Culinary usage

Garlic has been cherished for centuries due to its treasure trove of essential nutrients, establishing it as a cornerstone in many culinary traditions. Scientifically named *Allium sativum L.*, this crucial bulbous plant is grown worldwide and valued as a spice. Its cloves are brimming with phosphorus, potassium, calcium, magnesium, zinc, and vitamin C, while remaining low in fat, protein, and carbs, thereby enriching its nutritional benefits (55). For instance, garlic has been a global staple since ancient times, cherished for its sharp, pungent flavor as a seasoning or condiment. It plays a key role in countless dishes across diverse regions, from East and South Asia to Southeast Asia, the Middle East, North Africa, Southern and Eastern Europe, and parts of Latin America. In Latin American cuisine, garlic is a crucial component in traditional dishes like sofrito and mofongo, adding depth and richness to their flavors (56, 57).

In addition, garlic undergoes a fascinating transformation during roasting: what starts as a pungent, spicy ingredient mellows into a deep, rich, and subtly sweet flavor. Roasted garlic becomes a delightful spread for bread or a flavorful addition to sauces and dressings. To achieve this, wrap whole garlic bulbs in aluminum foil and bake them until they become soft. The cloves turn into a creamy, sweet delight, offering a simple yet nutritious treat (58, 59). Moreover, you can infuse oils with garlic cloves to add a burst of flavor. These aromatic oils are perfect for seasoning everything from vegetables and meats to breads and pastas. Simply crush or mince garlic and let it steep in the oil to create a fragrant infusion that enhances a wide range of dishes (60, 61). Garlic is frequently minced or sliced and sautéed in oil or butter to release its rich aromatic compounds. This technique is widely used as a flavorful base for cooking vegetables, meats, or pasta, enhancing the depth of the dish (61).

6. Medical significance

This medicinal plant has a storied history, stretching back through the ages as both a cherished culinary ingredient and a revered remedy. For centuries, its robust flavor has enhanced dishes, while its potent medicinal qualities have been harnessed to treat ailments and boost health. This versatile plant has long been celebrated not just for its taste but for its remarkable ability to support wellness and healing. Garlic is crucial for its medical benefits, notably in lowering blood pressure and cholesterol levels, which in turn reduces the risk of heart disease and stroke. Research indicates that garlic supplements can decrease LDL cholesterol by up to 10% in individuals with slightly elevated levels (62, 63, 68). Besides, Garlic offers a powerful combination of antimicrobial, antiviral, and antifungal properties, making it an excellent

supporter of the immune system. In particular, aged garlic extract has been proven to ease cold and flu symptoms more effectively, potentially shortening the duration of disease (62, 64, 65, 66). Furthermore, Garlic is a powerhouse when it comes to tackling inflammation. Packed with compounds such as allicin, diallyl sulfide, and other sulfur-rich elements, garlic has been proven to soothe inflammation. These natural ingredients help balance the body's inflammatory response and could shield you from diseases linked to chronic inflammation (67). Interestingly, Garlic could be your secret weapon in fighting cancer, especially for tricky digestive cancers like stomach and colorectal types. Its organosulfur compounds serve as protective agents, slowing down cancer cell growth, promoting their destruction, and preventing toxins that might cause problems (69). Moreover, Garlic functions as a powerful antioxidant by neutralizing free radicals that can damage cells. This antioxidant activity helps in preventing chronic illnesses like cancer, cardiovascular diseases, and neurodegenerative disorders (70, 71). It also might enhance insulin sensitivity and lower blood sugar levels in diabetics, though more human research is needed to confirm this. While eating garlic in typical amounts is generally safe, large doses can lead to bad breath, heartburn, and digestive problems. Garlic can also interact with certain medications, including blood thinners and HIV/AIDS treatments. Overall, garlic is a versatile ingredient with potential health benefits, but it's wise to consult a healthcare provider before using it medicinally, especially for ongoing conditions or with other medications (66, 72).

7. Nutritional value

Raw garlic packs about 149 calories per 100 grams, with a modest 6.36 grams of protein and just 0.5 grams of fat. The bulk of garlic's makeup is carbohydrates, delivering roughly 33 grams per 100 grams, including around 2.1 grams of dietary fiber (73, 74). Additionally, Garlic is a treasure trove of vitamins and minerals, featuring Vitamin C to boost your immune system, Vitamin B6 for metabolic and brain health, and manganese to aid in bone development and nutrient processing. It's also rich in selenium, an antioxidant essential for overall health. Plus, garlic offers a smattering of trace minerals like phosphorus, zinc, potassium, and magnesium (72, 75). We could hardly fit all the impressive nutritional benefits of garlic into this space, as it boasts over 200 chemical compounds. Among these are sulfur-rich elements like allicin, diallyl sulfide, and diallyl disulfide, which give garlic its powerful antimicrobial, anti-inflammatory, and antioxidant properties (72, 76).

8. Anti-Parasitic Activity of Garlic

Garlic undoubtedly stands out as a top antiparasitic herbal remedies, renowned for its ability to combat parasites that infect both humans and animals. This effectiveness is due to garlic's rich variety of antiparasitic compounds, as highlighted previously. At the core of garlic's strength is allicin, the active ingredient that emerges when garlic is crushed or chopped. Allicin's impressive antimicrobial range includes potent antiparasitic effects. It works by disrupting the vital processes of parasites—like blocking trypanothione reductase in *Trypanosoma brucei*—which ramps up oxidative stress and ultimately leads to the parasites' demise (40, 77).

What's truly impressive about garlic's anti-parasitic activity is its ability to exert significant cytotoxic effects on parasitic cells, such as those of *Leishmania*. Studies have demonstrated that garlic extracts can notably damage these primary parasitic cells, with one particular study showcasing their effectiveness in eradicating *Leishmania*. The notably low IC50 values highlight garlic's exceptional potency in eliminating pathogens, particularly parasites (77, 78). It's undeniable that garlic possesses a remarkable ability to boost and fortify the immune system of its hosts. This natural enhancement makes it much harder for parasites to establish infections or cause diseases. This immune-boosting property is especially valuable in aquaculture, where garlic is used to strengthen fish defenses against parasitic infections (79). Alongside allicin, garlic is rich in sulfur-containing compounds like ajoene and thiosulfinates, which play a crucial role in its anti-parasitic effects. These compounds compromise the cellular integrity of parasites and disrupt their metabolic processes, further enhancing garlic's ability to combat parasitic infections (35, 77, 80). Additionally, garlic extracts can trigger oxidative stress in parasites, causing significant cellular damage. This happens by boosting the production of reactive oxygen species (ROS), which in turn damage proteins, lipids, and DNA within the parasitic cells, ultimately leading to their destruction (80, 81). Furthermore, the compounds in garlic inhibit crucial enzymes necessary for the survival and reproduction of parasites. For instance, garlic can block oxidation and reduction enzymes that are vital for the metabolic functions of various parasites (77, 80). Despite garlic's potent anti-parasitic effects, the efficacy of garlic extracts often depends on the dosage. Higher concentrations lead to increased parasite mortality rates, with studies showing that cumulative mortality can reach up to 100% within a short period when exposed to sufficient concentrations of garlic juice (77, 79, 80). These mechanisms highlight garlic's potential as a natural alternative for managing parasitic infections in aquaculture, and possibly even in human health contexts. Further research is needed to fully understand the specific active compounds and their mechanisms of action against various types of parasites.

Additionally, the next section of the research will explore garlic's anti-parasitic effects on a variety of parasite species by reviewing numerous studies conducted in this field.

8.1. Antiparasitic activity of Garlic against *Entamoeba histolytica*

Entamoeba histolytica is a protozoan parasite that causes amoebic dysentery and is transmitted to humans through the fecal-oral route. This transmission occurs when a person ingests food or drink contaminated with quad-nucleate cysts. Once inside the human host, these cysts transform into the trophozoite stage, which is responsible for the disease. This stage can sometimes lead to symptoms such as bloody, mucous diarrhea, fever and abdominal pain (82, 83). It's estimated that *E. histolytica* impacts between 35 and 50 million people globally, leading to over 55,000 deaths annually. The disease is particularly common in regions with poor sanitation and is also a concern for travelers visiting these areas. Numerous infections remain asymptomatic, with only 10% to 20% of those infected showing symptoms (84.85). Garlic is recognized as a medicinal plant with proven efficacy as an anti-parasitic agent, particularly against *E. histolytica*. Detailed studies have shown that allicin, one of garlic's key active compounds, strongly inhibits the cysteine proteins produced by *E. histolytica*. These enzymes are crucial for the parasite's virulence and its ability to damage host tissues. By inhibiting these enzymes, allicin diminishes the parasite's impact on host cells, thereby reducing its pathogenic potential (86, 87). Studies have demonstrated that allicin can effectively inhibit the growth of *E. histolytica* trophozoites. It has been reported that the IC50 value—the concentration required to inhibit 50% of the parasite's growth—for allicin against E. histolytica is 59 micrograms per milliliter. This indicates that allicin exerts a significant impact even at relatively low concentrations, highlighting its potent anti-parasitic activity (87, 88). Moreover, numerous studies evaluating the anti-Entamoeba histolytica effects of garlic have demonstrated that garlic extracts can induce oxidative stress in *E. histolytica*, resulting in cellular damage and death. The elevated levels of reactive oxygen species (OS) disrupt the parasite's metabolic functions and compromise its cellular integrity (86). In addition, compounds in garlic may compromise the integrity of cell membranes in *E. histolytica*, causing leakage of cellular content and ultimately leading to cell death. This mechanism is especially effective against some parasites like *E. histolytica*, enhancing garlic's efficacy in combating these parasites (86). Given its effectiveness in inhibiting E. histolytica, garlic and its extracts are being studied as potential natural treatments for amoebic dysentery. Utilizing garlic could offer a complementary approach to existing pharmaceutical therapies, potentially reducing side effects and improving patient outcomes (89). It is important to note that a recent study conducted in 2023 aimed to evaluate the effectiveness of allicin, the active component in fresh garlic, against this parasite in the lab. The experiments involved groups of mice, with one group treated with metronidazole, another with allicin, and a third group receiving both treatments following infection. The results revealed that allicin effectively inhibited parasite growth, showing a significant improvement in the tissues of mice treated with the combined therapy compared to the other groups (90).

8.2. Antiparasitic activity of Garlic against *Giardia lamblia*.

Giardia lamblia, also known as *Giardia intestinalis* or *Giardia duodenalis*, is a flagellated protozoan parasite responsible for giardiasis, a common intestinal infection. It is widely recognized as one of the most prevalent intestinal parasites globally, particularly affecting children in developing countries (91, 92). Furthermore, this protozoon can cause either asymptomatic colonization or giardiasis, which can present as acute or chronic diarrhea. Studies have found its presence in up to 80% of water supplies sourced from lakes, ponds, and streams, and around 15% of filtered water samples. In developing countries, this parasite frequently leads to chronic diarrhea and impaired growth in children. High-risk groups for giardiasis include individuals with weakened immune systems, travelers visiting heavily endemic regions, and certain sexually active men who have sex with men. Members of these groups often exhibit symptoms of the infection (93, 94). These protozoa are most commonly transmitted via the fecal-oral route, which occurs when a person ingests food or drink contaminated with cysts. Once inside the host's body, these cysts transform into the vegetative trophozoite stage (95). Additionally, giardiasis is prevalent worldwide, particularly in regions suffering from inadequate sanitation and unsafe drinking water. The World Health Organization estimates that *Giardia lamblia* affects around 200 million people annually, with the infection leading to significant morbidity (96). On another hand, Garlic (*Allium sativum*) has been shown to possess potent anti-parasitic activities against a wide range of parasites, as demonstrated in both *in vitro* and *in vivo* experiments. Garlic extracts have been found to inhibit the growth of Giardia lamblia parasites. In one study, whole garlic extract exhibited an IC50 value of 0.31 mg/mL after 24 hours of exposure, indicating its effectiveness even at relatively low concentrations (97). In another study aimed at evaluating the effects of alcoholic extracts of Allium sativum on the intestinal flagellate Giardia lamblia, the extracts were administered orally for one week to assess their impact. Mice were divided into several groups, each receiving a different type of garlic extract. Various doses were tested. A separate group was treated with an anti-parasitic drug, metronidazole, while the control group was given an equal volume of normal saline. The results revealed that the cold water extract of garlic was the most effective, demonstrating a significant impact on Giardia lamblia with no side effects observed (98). It is worth noting that the effect of garlic extracts on Giardia can be attributed to the interaction of garlic compounds, particularly thioallyl compounds, with the thiol groups on the surface of the parasite. This interaction affects the rigidity of the cell

surface and its adhesion properties. Such interactions can lead to alterations in the cellular structure and internal membrane structures, ultimately contributing to the parasite's death (99). Furthermore, garlic extracts can induce oxidative stress in Giardia lamblia, leading to cellular damage and death. The increase in reactive oxygen species (ROS) disrupts the parasite's metabolic functions and compromises its cellular integrity (99). Allicin, a key active compound in garlic, inhibits the cysteine proteins produced by Giardia lamblia. These enzymes are crucial for the parasite's virulence and its ability to damage host tissues. By inhibiting these enzymes, allicin reduces the parasite's impact on host cells (99). In summary, the anti-parasitic activity of garlic against Giardia lamblia can be attributed to its ability to inhibit trophozoite growth, disrupt cellular integrity, induce oxidative stress, and block key enzymes essential for the parasite's survival. These findings suggest that garlic could serve as a natural therapeutic option for managing giardiasis, warranting further investigation into its efficacy and mechanisms of action.

8.3. Antiparasitic activity of Garlic against *Leishmania* Spp

Leishmania is a genus of parasitic protozoa responsible for leishmaniasis in humans and other mammals. This parasite exists in two primary forms: the promastigote, a flagellated, extracellular form found in the sandfly vector, and the amastigote, a non-flagellated, intracellular form residing within the mammalian host (100). Transmission predominantly occurs through the bite of an infected female sandfly, belonging to the genera Phlebotomus and Lutzomyia (100). Leishmaniasis is endemic across 89 countries, primarily in tropical and subtropical regions, with an estimated 1.5 to 2 million new cases occurring annually worldwide (101). The disease can be present in various forms, including cutaneous, mucocutaneous, or visceral leishmaniasis, depending on the Leishmania species and the host's immune response (102). Diagnosis includes identifying Leishmania parasites in tissue samples, while treatment is tailored to the clinical form and usually involves anti-leishmanial medications (102). Garlic (Allium sativum) has demonstrated significant antiparasitic activity against Leishmania species, which are responsible for leishmaniasis—a disease posing a substantial health challenge in various regions. Numerous studies have delved into the mechanisms and efficacy of garlic extracts in combating these parasites. For instance, a research project sought to investigate the antiparasitic efficacy, cytotoxic effects, and chemical composition of garlic (*Allium sativum)* essential oil (ASEO) in combating various Leishmania species. This oil exhibited potent activity, with IC50 values of 1.76 µg/ml for promastigotes, 3.46 µg/ml for axenic amastigotes, and 3.77 µg/ml for intracellular amastigotes. Detailed microscopic examination of the parasites treated with ASEO showed signs of plasma membrane disruption, an increase in lipid bodies, and structures resembling autophagy. These findings highlight the potential of garlic oil as a powerful therapeutic option for leishmaniasis (103). While in another study aimed to assess the effects of garlic extract on *Leishmania major* both in vivo and in vitro using a colorimetric assay. The data obtained from optical density (OD) measurements and IC50 values revealed that garlic extract concentrations of 4.6 µg/ml and 11.4 µg/ml exhibited significant inhibitory effects on the non-flagellated forms of *L. major* compared to the control drug, after 48 hours of incubation in vivo and in vitro, respectively (104). Undoubtedly, numerous research studies highlight garlic's antiparasitic activity against Leishmania. However, various mechanisms have been proposed to explain how garlic exerts this effect. One such mechanism suggests that garlic extracts inhibit enzymes like trypanothione reductase, which is crucial for the survival of trypanosomatids, including Leishmania. This inhibition leads to increased oxidative stress within the parasite, ultimately resulting in cell death (77, 104). Furthermore, another mechanism explaining garlic's antiparasitic effect includes enhancing the immune response against leishmaniasis. Garlic boosts the expression of immune-related genes such as IFN-γ and iNOS in macrophages, which are crucial for combating *Leishmania* infections. This immunomodulatory effect improves the host's ability to effectively fight off the infection (105, 106). In conclusion, garlic exhibits promising antiparasitic activity against Leishmania. Through various mechanisms, including direct toxicity to the parasites and enhancement of the immune response, garlic demonstrates effectiveness in both in vitro and in vivo studies. This efficacy highlights its potential role in managing leishmaniasis and offers hope for developing effective therapeutic strategies.

8.4. Antiparasitic activity of Garlic against *Trypanosoma Spp*

Trypanosomes are a genus of single-celled parasitic protozoa classified under the *Kinetoplastida* class, encompassing several species responsible for severe diseases in humans and animals, such as African sleeping sickness and Chagas disease. These parasites are primarily transmitted through insect vectors. For instance, *Trypanosoma brucei*, which causes African sleeping sickness, is spread by the tsetse fly (*Glossina* spp.), while *Trypanosoma cruzi*, the causative agent of Chagas disease, is transmitted by triatomine bugs (107, 108). Garlic (*Allium sativum*) has been extensively studied for its antiparasitic properties, particularly against trypanosome species responsible for serious diseases such as African sleeping sickness, caused by *Trypanosoma brucei*, and Chagas disease, caused by *Trypanosoma cruzi*. The active compounds in garlic, especially sulfur-containing metabolites like allicin, play a crucial role in its antiparasitic effects. In *in vitro* study, garlic has shown remarkable effectiveness against *Trypanosoma brucei*, achieving IC50 values of approximately 33.28 µg/ml. This reflects garlic's potent capability to eliminate parasites at low concentrations, underscoring its notable antiparasitic potential (77). On the other hand, animal studies have demonstrated that garlic

extracts are effective in reducing parasitemia (the presence of parasites in the blood) and improving blood parameters in infected mice. For instance, one study found that a dose of 500 mg/kg of garlic extract significantly reduced parasitemia and enhanced packed cell volume, outperforming conventional treatments (109). As previously mentioned, garlic extracts have been shown to irreversibly inhibit the enzyme trypanothione reductase (TbTR), which is crucial for the survival of trypanosomes. This inhibition disrupts the oxidative-reductive balance within the parasites, leading to increased oxidative stress and, ultimately, cell death (77). Moreover, garlic extracts can diminish the mitochondrial membrane potential in trypanosomes, indicating mitochondrial dysfunction. This effect contributes to the destruction of the parasites and significantly impacts their energy metabolism and survival abilities (77). In summary, garlic demonstrates notable activity against parasites causing trypanosomiasis. Through mechanisms such as enzyme inhibition and mitochondrial dysfunction, garlic emerges as a promising treatment. Its proven efficacy in both laboratory and in vivo studies highlights its potential role in effectively managing trypanosome infections.

8.5. Antiparasitic activity of Garlic against *Cryptosporidium parvum*

Cryptosporidium parvum is a protozoan parasite responsible for cryptosporidiosis, a diarrheal ailment impacting humans and animals. This parasite ranks among the most prevalent waterborne pathogens, spreading via contaminated or improperly treated water supplies. Infected individuals may experience acute watery diarrhea, abdominal cramps, nausea, and vomiting. Particularly vulnerable are children, the elderly, and those with compromised immune systems, who face a heightened risk of severe complications (110, 111). Despite a reported rise in global cryptosporidiosis cases to roughly 3 per 100,000 individuals, clinical evidence suggests the true prevalence might be 100 times higher. This large gap indicates a potentially much higher actual infection rate than currently documented. In industrialized nations, the disease is less prevalent compared to developing countries, where many people lack access to essential drinking water and sanitation facilities. These conditions foster the continued transmission of cryptosporidiosis in regions with poor health infrastructure (112). Garlic (*Allium sativum*) has shown promising antiparasitic effects against Cryptosporidium parvum, a protozoan parasite responsible for cryptosporidiosis in both humans and animals. Numerous studies have investigated the potential of garlic as a therapeutic agent against C. parvum infection. Research reflects positive results, indicating that garlic possesses properties that may aid in combating this parasite and mitigating its health impacts. For instance, a study investigated the therapeutic effects of garlic and onion oils on experimental cryptosporidiosis in mice. The mice were administered oral doses through a gavage tube daily until the conclusion of the experiment on the 15th day post-treatment. The efficacy of the oils was determined by counting the number of oocysts in the feces of the infected groups and conducting a histopathological examination of the ileum at the study's end. The findings revealed that both garlic and onion oils were effective against cryptosporidiosis, with garlic oil demonstrating superior efficacy compared to onion oil (113). In another study aimed at assessing the preventive and therapeutic efficacy of Allium sativum (garlic) against Cryptosporidium infection in both immunocompetent and immunocompromised mice, the results indicated a significant increase in oocyst numbers in the feces and ileal sections of the immunocompromised mice compared to the immunocompetent group. Garlic effectively eradicated Cryptosporidium oocysts from the feces and intestines of immunocompetent mice that were given garlic two days before infection. Moreover, all other experimentally infected groups showed a significant reduction in oocyst numbers compared to their corresponding infected control groups (114). In addition, an in vivo study in pigs showed that administering garlic at a dose of 180 mg/kg/day for 10 days reduced the prevalence of *Cryptosporidium parvum*, although the effect was modest. The study also demonstrated that garlic's antiparasitic activity might be due to its content of polyphenols, tocopherols, flavonoids, sterols, sesquiterpene lactones, and sulfoxides (115). Additionally, other studies have shown that garlic extract effectively reduces the shedding of *Cryptosporidium parvum* oocysts and enhances the histological structure of both the stomach and spleen. These findings underscore the potential of garlic as a promising treatment against this parasite (116). Overall, the antiparasitic effects of garlic against *Cryptosporidium parvum* are largely attributed to its phytochemicals, including allicin and organosulfur compounds, which exhibit antimicrobial properties and may boost the immune system. These studies indicate that garlic could serve as a promising natural therapeutic alternative for treating cryptosporidiosis, offering potential benefits in improving patient health and mitigating drug resistance.

8.6. Antiparasitic activity of Garlic against *Plasmodium* spp

Malaria is a life-threatening illness caused by Plasmodium parasites, transmitted to humans through bites from infected female Anopheles mosquitoes. It is marked by symptoms such as fever, chills, and flu-like illness, and can result in severe complications if not treated promptly (117, 118). In severe cases, malaria can cause complications such as anemia, respiratory distress, organ failure, and death, particularly among vulnerable populations such as young children and pregnant women (118, 119). In addition, Malaria is endemic in many tropical and subtropical regions, with the highest burden in Sub-Saharan Africa, where over 90% of malaria deaths occur. In 2022, there were approximately 249 million cases of malaria worldwide, leading to around 608,000 deaths. The disease disproportionately affects children under the age of five, who account for a significant portion of malaria-related fatalities (120, 121).

Unfortunately, malaria remains a major global health challenge, worsened by factors like climate change, drug resistance, and disparities in access to healthcare. Continued efforts are essential to combat this disease and move towards its eradication (121, 122). Research has shown that garlic (*Allium sativum*) possesses significant anti-malarial properties, largely attributed to its active compound, allicin. A study by researchers at the Indian Institute of Science demonstrated that garlic oil can boost the efficacy of the commonly used anti-malarial drug artemether when used in combination therapy. In experiments on mice infected with *Plasmodium berghei*, the combination of garlic oil and artemether not only extended the survival time of the infected mice but also achieved a 100% survival rate over a prolonged period, significantly outperforming control groups that did not receive garlic oil (123). Furthermore, allicin, a biologically active compound from garlic, has been tested for its potential to inhibit malaria infection. The results are promising, particularly in its role as a cysteine protease inhibitor (124). Additionally, another study evaluated the effect of a hydroalcoholic extract of wild garlic on mice infected with the malaria parasite Plasmodium berghei. The study involved 45 male mice, and the results showed that the wild garlic extract had the most significant effect at a dose of 800 mg/kg, inhibiting parasite growth by 92.4% compared to the control group (125). These results suggest that garlic and its derivatives could be effective adjuncts in malaria treatment, potentially lowering the required doses of conventional medications and mitigating issues related to drug resistance (123).

8.7. Antiparasitic activity of Garlic against *Enterobius vermicularis*

Human pinworms, scientifically known as *Enterobius vermicularis*, are parasitic nematodes that primarily inhabit the human intestines, particularly in children. These cylindrical worms are distinguished by their elongated bodies, with adult females measuring 8 to 13 mm in length and males 2 to 5 mm. The term "pinworm" originates from the pointed tail of the female, which is used to deposit eggs around the anal area, leading to intense itching and discomfort (126, 127). Infections with human pinworms are often asymptomatic, but symptoms can include perianal pruritus, insomnia, irritability, and, in some cases, secondary bacterial infections resulting from scratching (128). *Enterobius vermicularis* is widely distributed globally, with a higher prevalence among children due to behaviors like thumb sucking and inadequate hygiene practices. However, infection does not exclusively indicate poor hygiene, as it can affect individuals across different living conditions (129). Garlic (Allium sativum) has demonstrated promising antiparasitic activity against the pinworm Enterobius vermicularis, a common intestinal parasite in humans. A study revealed that 74.64% of individuals with pinworm infections achieved complete recovery within three days of using a garlic suppository. Conversely, 25.35% of patients remained infected after three days. By five days, only 0.11% of patients still had the infection, and no cases were reported after seven days of treatment (130). Additionally, another impressive study found that a standard dose of garlic capsules (400 mg twice daily for three consecutive days) was effective in completely eradicating *Enterobius vermicularis* infection in 100% of patients (131). Garlic treatment demonstrated a lower recurrence rate compared to mebendazole treatment. Among patients treated with garlic, only 3 experienced relapses, while 25 patients in the mebendazole group had relapses. Approved anthelmintic medications like mebendazole, albendazole, and other benzimidazole derivatives can eliminate both adult worms and eggs. However, albendazole is expensive and raises concerns about teratogenicity and potential liver toxicity (130, 131). There is no doubt that garlic has an anti-pinworm effect, primarily due to its role in enhancing the production of antioxidants. This action may help reduce the number of parasitic eggs and subsequently lower the birth rate of new worms. Additionally, the antimicrobial activity of garlic and onion extracts has been shown to be effective against various parasites (77, 80). In conclusion, garlic demonstrates promising antiparasitic activity against Enterobius vermicularis and may serve as an effective alternative treatment with a lower recurrence rate compared to conventional medications.

8.8. Antiparasitic activity of garlic against *Toxoplasma gondii*

Toxoplasma gondii is a protozoan coccidian parasite that causes the disease known as toxoplasmosis. This remarkable parasite has the ability to infect a wide variety of warm-blooded animals, including humans. Yet, it can exclusively reproduce sexually within the intestines of felines, particularly domestic cats. The parasite's life cycle contains both asexual and sexual stages, with oocysts being shed in the feces of infected cats. These oocysts can contaminate soil, water, and food sources, emphasizing the absolute necessity for careful monitoring to mitigate the potential infection (132, 133).

Humans can get infected by consumption of meat that has tissue cysts. Moreover, accidentally ingesting oocysts from contaminated soil, water, or surfaces—often connected to handling cat litter or gardening without good hygiene—is another common route. In addition, pregnant women who contract the parasite can transmit it to their fetuses as well, potentially causing severe issues such as neurological damage and other complications. This mode of transmission, known as vertical transmission, is significant and should not be ignored (132, 135). *Toxoplasma gondii* is a global phenomenon, with about one-third of the world's population estimated to be infected at some point in their lives. The infection's prevalence, however, shows significant variation, influenced by factors like geographic location, dietary practices, and cat exposure (134, 135). Numerous studies have underscored garlic's significant benefits in combating

Toxoplasma gondii. One such study examined the chemical composition and both in vitro and in vivo effects of Allium sativum essential oil (ASEO) against the Toxoplasma gondii RH strain. The study's findings indicated that ASEO demonstrated promising therapeutic effects against acute toxoplasmosis in mice, resulting in increased survival times and a reduction in the parasite's presence within tissues. These positive outcomes are attributed to the anti-toxoplasmic properties of A. sativum, primarily due to its organosulfur compounds and their immune-enhancing effects, which stimulate immune cells and regulate cytokine secretion (136). To explain these findings, the study showed that ASEO significantly improved lipid peroxidation (LPO) and nitric oxide (NO) levels in mice infected with Toxoplasma gondii, highlighting garlic's role as an anti-inflammatory agent that protects the liver. Real-time PCR results indicated a substantial reduction in the gene expression levels of IL-1β and IFN-γ mRNA in the infected mice, suggesting that ASEO effectively mitigates inflammation (136). Another study including experimental mice demonstrated that both garlic extract and garlic tablets effectively treated murine toxoplasmosis, with no significant difference in efficacy between the two forms. The results showed that garlic extract prolonged the survival of mice infected with a lethal dose of *Toxoplasma gondii* and reduced the parasite's presence in tissues. The optimal dose of garlic extract for enhancing survival time was found to be 200 mg/kg. These benefits are largely attributed to garlic's antibacterial and immunomodulatory properties (137). In summary, garlic and its essential oil demonstrate potent antiparasitic activity against Toxoplasma gondii and other parasitic infections. This effectiveness is credited to their anti-inflammatory properties, immune-modulating effects, and the down-regulation of pro-inflammatory cytokines. Consequently, garlic emerges as a promising natural treatment alternative for toxoplasmosis and a variety of other parasitic diseases.

8.9. Antiparasitic activity of Garlic against *Schistosoma mansoni*

Schistosoma mansoni is a flatworm parasite responsible for intestinal schistosomiasis, affecting around 54 million people each year, predominantly in sub-Saharan Africa and the Middle East. The parasite's complex life cycle includes five distinct body forms. It reproduces asexually within its snail host, typically from the *Biomphalaria* species, and sexually within its vertebrate host, primarily humans (138). This parasite can lead to numerous health issues for the infected individual as its eggs penetrate the intestinal wall and are expelled in the stool. However, some eggs become trapped in the liver and other organs, resulting in granulomas and fibrosis. These can cause intestinal, hepatic, and splenic complications, including diarrhea, abdominal pain, portal hypertension, and liver failure (138, 139). Garlic (Allium sativum) has revealed encouraging antiparasitic effects against *Schistosoma mansoni*, the parasite responsible for intestinal schistosomiasis. Numerous studies have investigated the potential of garlic and its active compounds in diminishing the burden of this parasite, highlighting its considerable promise as a natural treatment for the disease. In a study evaluating the antiparasitic effects of garlic on Schistosoma mansoni, researchers administered garlic extract (50 mg/kg body weight per mouse) orally every other day at a consistent time. After seven weeks of infection, adult schistosomes were collected through perfusion, and the mice's livers were processed for DNA extraction and Random Amplified Polymorphic DNA Polymerase Chain Reaction (RAPD-PCR) amplification. The findings revealed that garlic did not induce significant changes in the *Schistosoma* genome. However, Schistosoma mansoni infection caused genetic alterations in the mice's DNA, and garlic was shown to significantly mitigate these changes (140). Besides, one study found that garlic treatment led to a significant reduction in both egg and worm counts. Additionally, garlic induced numerous microscopic structural changes in the remaining worm membranes, including rupture of the tegument, edema, blistering, ulceration, and the formation of vacuoles in other membranous structures. These findings suggest that garlic is a promising and effective therapeutic agent for combating this parasite (141). Consistent with previous findings, prophylactic treatment with garlic and allicin in infected mice led to a significant reduction in worm burden. Additionally, there was a notable decrease in serum levels of liver fibrosis markers and pro-inflammatory cytokines. Although praziquantel (PZQ) was found to be the most effective at reducing worm counts, with results aligning with those commonly observed with PZQ, the study concluded that homogenized garlic powder and allicin hold promise as complementary therapies to be used alongside PZQ (142). It’s worth noting that garlic's antiparasitic effects are attributed to several mechanisms. These include the stimulation of nitric oxide production, which helps destroy the parasites, and immunomodulation. Garlic shifts the cytokine response from a Th2-mediated pattern, which is associated with granuloma formation, to a Th1-mediated response that enhances immune resistance (142). Garlic and its active compounds display notable antiparasitic, anti-inflammatory, and antioxidant properties against Schistosoma mansoni infection. These attributes make garlic a encouraging candidate for further research and potential use as a complementary treatment in schistosomiasis control efforts.

8.10. Antiparasitic activity of Garlic against *Hymenolepis nana*

Hymenolepis nana, commonly known as the dwarf tapeworm, is a small intestinal cestode (tapeworm) that primarily infects humans and rodents. It is one of the most widespread tapeworms globally, especially affecting children in regions with inadequate sanitation and hygiene. The adult worm typically measures between 15 to 40 mm in length and features a scolex with four suckers and a retractable rostellum equipped with hooks (143, 144). Infections with *Hymenolepis nana* are often asymptomatic, but severe cases can manifest with symptoms such as abdominal pain, diarrhea, anorexia,

and pruritus ani. Because its symptoms closely resemble those of other intestinal infections, *H. nana* infections may occasionally be misdiagnosed as pinworm infections (144). Hymenolepis nana is a globally distributed parasite, with higher prevalence rates observed in tropical and subtropical regions. The infection is notably prevalent among children in impoverished communities with inadequate hygiene practices. In the United States, while the overall prevalence is relatively low, it can be higher within institutionalized populations (143, 144). Garlic (*Allium sativum*) has been shown to have remarkable antiparasitic effects against Hymenolepis nana, a tapeworm that commonly infects humans, particularly in regions with inadequate sanitation. Several studies have focused on the potential of garlic and its active compounds in mitigating the burden of this parasite.

For instance, one study investigated the nematocidal and therapeutic effects of allicin derivatives against *Hymenolepis nana* both *in vitro* and *in vivo*. The findings revealed that allyl disulfide (DADS), a compound in garlic, exhibited significant nematocidal activity. *In vitro*, DADS reduced the motility, caused mortality, and damaged the body parts of the worms. *In vivo*, the study showed that DADS influenced cytokine levels in BALB/c mice post-infection, increasing IFN-γ, decreasing IL-2, IL-4, IL-6, and IL-13, and having no significant effect on IL-5, IL-10, and IL-12 p70. These results highlight garlic's potential as a medicinal plant with active components that could be developed into effective antimicrobial or antiparasitic drugs (145). In another study, the effect of serial dilutions of raw garlic extract (Allium sativum) on adult Hymenolepis nana was examined to determine the minimum lethal concentration, which was found to be 1/20. Additionally, garlic was tested as a treatment for 10 children infected with H. nana. The treatment involved administering 5 ml of raw garlic extract in 100 ml of water, given twice daily, or using a commercial preparation of garlic (0.6 mg capsules), with two capsules taken twice a day for 3 days. The study concluded that garlic was effective, safe, and reduced the duration of treatment (146). In conclusion, garlic and its bioactive compounds, particularly DADS and DATS, demonstrate significant cestocidal and therapeutic effects against Hymenolepis nana infections, both in vitro and in vivo. The antiparasitic properties of garlic highlight its potential as a valuable candidate for further research and as a complementary treatment option in managing H. nana infections. Lastly, Table No. 3 below summarizes the effects of garlic as an antiparasitic agent on some of the studied parasites.

Table 3 The effects of garlic as an antiparasitic agent on some of the studied parasites as well as the mechanisms of action.

Parasite	**Mechanisms of Action**	**Ref**
Entamoeba histolytica	Inhibition of Cysteine Proteinases	86
	Disruption of Cellular Integrity	34
	Induction of Oxidative Stress	147
	Interference with Metabolic Processes	148
Giardia duodenalis	Disruption of Cell Membrane Integrity	99
	Inhibition of Enzymatic Activity	149
	Induction of Oxidative Stress	149
	Alteration of Cytoskeletal Structures	99
	Impact on Flagellar Activity	150
Leishmania Spp	Immunomodulatory Effects	151
	Nitric Oxide (NO) Production	152
	Cytotoxic Effects on Parasites	153
	Alteration of Cytokine Profiles	151
Trypanosoma Spp	Inhibition of Trypanothione Reductase	77
	Decrease in Mitochondrial Membrane Potential	77
	Synergistic Effects with Anti-Trypanosomal Drugs	77
	Antioxidant and Hepatoprotective Properties	154
Cryptosporidium parvum	Eradication of Oocysts	114
	Active Compounds: sulfur-containing compounds, particularly diallyl disulfide (DADS) and diallyl trisulfide (DATS).	155
	Enhancement of Immune Response	155

	Reduction of Inflammation	113
Plasmodium spp	Inhibition of Cysteine Proteases	124
	Disruption of Mitochondrial Function	124
	Immune System Modulation	156
	Synergistic Effects with Anti-Malarial Drugs	157
Enterobius vermicularis	Expulsion of Worms	131
	Inhibition of Egg-Laying	158
	Clinical Efficacy	131,158
Toxoplasma gondii	Enhancement of Immune Response	137
	Direct Anti-Parasitic Effects	137
	Reduction of Parasite Load	137
Schistosoma mansoni	Action of Allicin	159
	Disruption of Tegumental Integrity	160
	Immune System Modulation	161
	Antioxidant Properties	160,161
Hymenolepis nana	Cestocidal Activity of Allicin and Its Derivatives	145
	Disruption of Tegumental Integrity	145
	Immune Modulation	145
	Reduction of Egg Production	146

9. Conclusion

In conclusion, garlic (*Allium sativum*) can be considered as a highly promising natural remedy for parasitic infections, owing to its robust antiparasitic properties. This review emphasizes Garlic's effectiveness against a diverse range of parasites and further emphasizes the critical role of its essential compounds, particularly allicin. Even though current research indicates substantial potential, further studies and clinical trials are absolutely necessary to validate garlic's effectiveness, determine optimal dosages, and assess its role as a complementary treatment. Ultimately, garlic stands out as a valuable natural option in the ongoing battle against parasitic diseases, offering hope for more accessible and holistic treatment strategies.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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