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Assessment of potential use of garlic (*Allium sativum*) against growth of microbes

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Abstract

Garlic (*Allium sativum*) is cultivated worldwide for its medicinal and nutritional value. Garlic is an effective antibacterial, antifungal, antiprotozoal and antiviral agent. Garlic contains organosulfur compounds which impart antimicrobial property. Garlic is known to be highly effective in reducing growth of bacteria. Garlic bulb contains organosulfur compound, allicin, which is responsible for the efficacy of garlic against the growth of microbes. This compound can hinder the formation of bacterial acetyl-CoA, a precursor required for metabolic activities in bacteria. The present review indicates that garlic exhibit considerable inhibitory effect on microbial growth. Thus garlic can be used as a sustainable alternative to treat diseases and provide a solution to minimize our dependence on chemical-based drugs in future.

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INTRODUCTION

Garlic (*Allium sativum*) is considered as a magical plant for its valuable therapeutic properties. Garlic has a worldwide production of about 28.16 million tons and covers an agricultural field area of about 1.57 million ha (FAO, 2019). China, India, Republic of Korea, Egypt and the United States of America are the main producer of garlic worldwide (FAO, 2019). Garlic is also cultivated in Russia, Myanmar, Spain, Bangladesh and Ukraine FAO (2019). Worldwide production of garlic has continuously increased in the past 10 years. This increase in the production and consumption of garlic can be attributed to nutritional, medicinal and functional properties of this plant.

Allium sativum is botanically classified in kingdom Plantae, order Asparagales, family Amaryllidaceae, and genus *Allium* (Foroutan-Rad *et al.*, 2017). Garlic is broadly utilized for flavouring due to its sharp taste and peculiar smell (Yayeh *et al.*, 2017). Garlic improves taste and make food more edible (Higdon *et al.*, 2008). Garlic is also well known for medicinal effects and is widely used as a cure of diseases (Rivlin, 2001). Medicinal value of garlic has been documented even in the oldest reports, Ebers Papyrus from Egypt (Block, 1985). Garlic is a highly effective natural source to treat parasite infection. It is used in esophagus infections, gastric tract ailments and fungal diseases.

Chemicals of this plant act as a natural antibiotic in the human body. These chemicals can selectively inhibit harmful bacteria without affecting useful bacterial flora. Use of garlic against the growth of microbes has been studied in detail by many authors (Corzomartinez *et al.*, 2007). Moreover, garlic has also been observed to be cardioprotective as it can significantly lower cholesterol and triglyceride formation (Brace, 2002). It helps in reducing the aggregation of blood platelets and lower blood pressure (Gorinstein *et al.*, 2007). Application of garlic has also been associated with the inhibition of cancer cell growth (Weisberger and Pensky, 1958).

The medicinal property of the garlic is associated

with organosulfur compounds present in it. The present paper is an attempt to summarize research on the assessment of the antimicrobial property of garlic. This paper also highlights the importance of organosulfur compounds in imparting antibacterial, antifungal, antiviral and antiparasitic property to garlic.

Phytochemicals in garlic

The main composition of garlic includes 58.58% water along with carbohydrates and dietary fiber (Table 1). Garlic is a rich source of flavonols and organosulfur compounds. These compounds are responsible for the medicinal property of garlic.

Garlic consumption is associated with a reduction of diseases like cancer, stomach infection etc. (Iciek *et al.*, 2009). This reduction of diseases and medicinal benefits are possible because garlic is a rich source of organosulfur chemicals (Iciek *et al.*, 2009). Intact garlic bulbs contain a high amount of alliin (S-allylcysteine sulfoxide) (Amagase, 2006). Enzyme alliinase is released after crushing, grinding or cutting of garlic bulb. Enzyme alliinase can catalyze the conversion of alliin into allicin (Figure 1). Allicin is the compound which imparts distinctive spicy aroma to garlic. However, instability of allicin is responsible for its further conversion into stable compounds like diallyl sulfide, diallyl disulfide, diallyl trisulfide and diallyl tertasulfide (Figure 1). It has also been observed that the concentration of these sulfur compounds varies with factors like temperature and time (Brodnitz *et al.*, 1971).

Garlic is known to possess organic selenium compounds and steroidal saponins (Lanzotti, 2006). Both these compounds are highly efficient in minimizing the growth of cancer cells (Arnault and Auger, 2006). Garlic contains a high amount of selenium compound like g-glutamyl-Se-methylselenocysteine and Se-methylselenocysteine.

Efficacy of garlic as an anti-bacterial agent

Garlic is widely known for its antibacterial effects (Ankri and Mirelman, 1999; Bayan *et al.*, 2014). Research studies have proved that garlic can hinder the growth of the vast spectrum of bacteria. For example, (Adler and Beuchat, 2002) observed that the addition of garlic in butter can reduce survival of *Escherichia coli*, *Salmonella* and *Listeria monocytogenes*. Similarly, a sharp zone of inhibition of *Penicillin* was observed in-the cylinder plate assay method when tested with the garlic clove (Cavallito and Bailey, 1944). In another study, garlic concentration of 10% (w/v) was observed to be lethal against *Escherichia coli* and *Salmonella typhimurium* (Johnson and Vaughn, 1969). Antibacterial properties of garlic were also elucidated by (Sharma *et al.*, 1977; Witt *et al.*, 1979) Wit *et al.* (1979) reported that garlic oil was very efficient in reducing the toxicity of *Clostridium botulinum* in meat. Similarly, garlic extract inhibited the growth of thirty strains of *Mycobacterium* (Delaha and Garagusi, 1985). Recently, garlic was observed to significantly inhibit the proliferation of bacteria *Proteus mirabilis* and *Escherichia coli* (Petropoulos *et al.*, 2018) . *Helicobacter pylori* which is associated with stomach cancer and ulcers was found to be minimum after consumption of garlic-based diet (O'gara *et al.*, 2000; Sivam, 2001). In another research study, garlic extract with a high concentration of allicin was found to hinder multiplication of 13-gram-positive bacteria, gram-negative bacteria and fungi (Bakri and Douglas, 2005). *Streptococcus mutans* and *Porphyromonas gingivalis* were most inhibited by garlic extract. Studies have also proved that garlic negatively affects the growth of harmful enterobacteria, but it shows no effect on the growth of beneficial microflora. For example, disk diffusion assays revealed that garlic extract inhibits the growth of *Bifidobacterium longum*, whereas no effect was observed on *Lactobacillus acidophilus* (Altuntas and Korukluoglu, 2019). Table 2 indicates the consequences of garlic application on the growth of different bacteria.

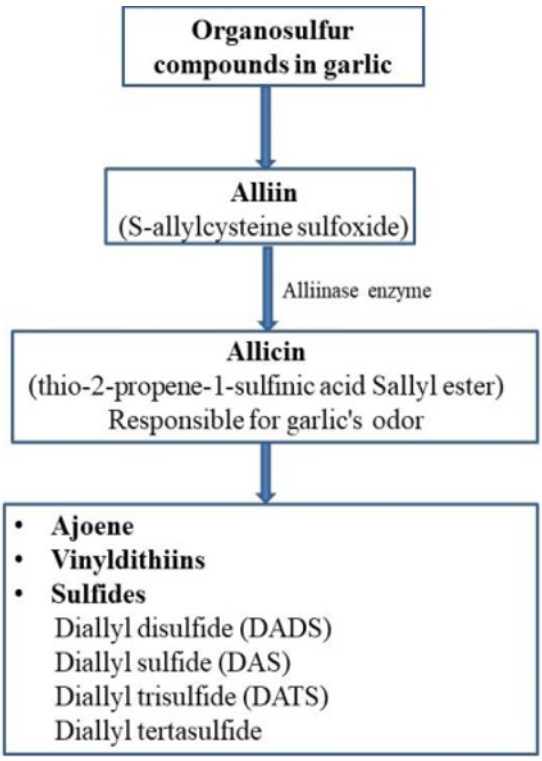

Figure 1: Diagrammatic representation of organo sulfur compounds and their conversion in garlic

Table 1: Nutritional composition of garlic (USDA, 2019)

Nutrient	Unit	Value per 100g
Water	g	58.58
Protein	g	6.36
Total lipid	g	0.50
Carbohydrates	g	33.06
Fibres, total dietary	g	2.1
Sugars	g	1
Fatty acids, total saturated	g	0.089
Fatty acids, total polyunsaturated	g	0.249
Fatty acids, total mononsaturated	g	0.011

Microbial inhibition with garlic usage is correlated with the presence of allicin in garlic bulb (Salehi *et al.*, 2019). Though more studies are required to elucidate the mechanism by which allicin inhibits microbial growth, some finding have reported that allicin can alter physiological processes in bacteria. These physiological processes include RNA and lipid formation in a cell (Rahman, 2007). Allicin can also interfere with the normal process of acetyl-CoA formation in bacteria. This organosulfur compound can prevent initiation of precursor enzyme, acetyl-CoA synthetases. These physiological changes weaken bacterial immune mechanism, accelerate the process of apoptosis and ultimately disrupt bacteria cell (Salehi *et al.*, 2019).

Efficacy of garlic as anti-protozoal agent

Garlic shows a strong inhibitory effect on multiplication of various parasites. For example, (Davis, 2003) suggested that infection of *Scedosporium prolificans* could be treated with the usage of garlic. Similarly, ajoene chemical of garlic was observed to be highly effective in curing an infection of *Tinea pedis* (Ledezma *et al.*, 2000). Garlic was analyzed to be a potent inhibitor of several parasites like *Opalina ranarum*, *Entamoeba histolytica, Leishmania* (Reuter *et al.*, 1996) . In an experiment, *A. sativum* was observed to be an inhibitory agent for a parasite, *Haemonchus contortus* (Landín *et al.*, 2016). Inhibitory activities of garlic on giardia were tested in a clinical trial on patients that had giardiasis (Soffar and Mokhtar, 1991). Garlic consumption helped in reduction of the giardiasis in a single day. Thus garlic is a better alternative for the treatment of giardiasis as compared to synthetic pharmaceuticals. In an experiment, garlic solution damaged all *Cryptosporidium* oocysts in stool and ileum sections of mice (Gaafar, 2012). The study suggests that garlic could provide the key to control *Cryptosporidium* infection. A study by (Raza *et al.*, 2016) provides evidence that garlic is beneficial to minimize *Ascaridia galli* diseases. Therefore garlic can act as a natural agent for control of this parasite and could prove immensely useful for the health of poultry birds. Similar observations were also made by (Velkers *et al.*, 2011). It has been observed that even essential oil derived from garlic could be highly effective to kill parasitic worms (Singh and Nagaich, 2000). (Mantawy *et al.*, 2011) observed less number of *Schistosoma mansoni* with an application of garlic on infected mice. Garlic can also be lethal against several *Leishmania* species (Foroutan-Rad *et al.*, 2017). Table 3 highlight numerous research studies which support the fact that garlic plays a crucial role in controlling the growth of parasites.

Efficacy of garlic as an anti-fungal agent

Many research studies have provided strong evidence in support of the fungicidal property of garlic. For example, electron microscopic investigations revealed that addition of garlic can damage the cell membrane of *Candida albicans* and thereby inhibit the multiplication of this fungus (Lemar *et al.*, 2002). Strong evidence in support of a reduction in the growth of *Candida* with garlic application was also provided by (Yousuf *et al.*, 2011). Apart from *Candida*, many researchers have analyzed the effect of garlic on other fungi. Garlic concentration was observed to be lethal for Cryptococcus neoformans (Fromtling and Bulmer, 1978). In another interesting study, garlic application was observed to show inhibitory effects on many molds (Tansey and Appleton, 1975). It has also been observed that the addition of garlic reduces susceptibility to airborne fungus-like *Botrytis cinerea* (Lanzotti *et al.*, 2012). Garlic extracts were observed to be effective against *Neofabraea alba* (Daniel *et al.*, 2015). This study also confirmed that garlic can be used as a lethal agent for fungi like *Botrytis cinerea* and *Penicillium expansum* (Daniel *et al.*, 2015) . The garlic extract at 80% concentration completely inhibited the growth of pathogenic fungi, *Phomopsis* (Sittisart *et al.*, 2017).

Table 2: Summary of research studies on the role of garlic as an antibacterial agent

Bacteria	Effect	References
Bacillus subtulis	Decrease	(Sharma *et al.*, 1977)
Bifidobacterium longum	Decrease	(Altuntas and Korukluoglu, 2019)
Clostridium	Decrease	(Wit *et al.*, 1979)
Corynebacterium diphtheriae	Decrease	(Cahayani *et al.*, 2019)
Escherichia coli	Decrease	(Petropoulos *et al.*, 2018)
Helicobacter sp.	Decrease	(O'gara *et al.*, 2000)
Helicobacter pylori	Decrease	(Sivam, 2001)
Lactobacillus acidophilus	Decrease	(Altuntas and Korukluoglu, 2019)
Mycobacterium sp.	Decrease	(Delaha and Garagusi, 1985)
Porphyromonas gingivalis	Decrease	(Bakri and Douglas, 2005)
Proteus mirabilis	Decrease	(Petropoulos *et al.*, 2018)
Salmonella typhimurium	Decrease	(Johnson and Vaughn, 1969)
Streptococcus mutans	Decrease	(Bakri and Douglas, 2005)

Table 3: Research studies conducted to analyze the effect of garlic application on parasite growth

Parasite	Effect	References
Ascaridia galli	Decrease	(Singh and Nagaich, 2000; Velkers *et al.*, 2011; Raza *et al.*, 2016)
Cryptosporidium	Decrease	(Gaafar, 2012)
Haemonchus contortus	Decrease	(Landín *et al.*, 2016)
Heterakis gallinarum	Decrease	(Singh and Nagaich, 2000)
Scedosporium prolificans	Decrease	(Davis, 2003)
Tinea pedis	Decrease	(Ledezma *et al.*, 2000)
Schistosoma mansoni	Decrease	(Mantawy *et al.*, 2011)
Leishmania sp.	Decrease	(Foroutan-Rad *et al.*, 2017)

Table 4: Outcome of garlic application on fungal growth

Fungi	Effect	Reference
Candida	Decrease	(Yousuf *et al.*, 2011)
Cryptococcus	Decrease	(Fromtling and Bulmer, 1978)
Rhodotorula	Decrease	(Tansey and Appleton, 1975)
Fusarium	Decrease	(Kutawa *et al.*, 2018)
Rhizopus	Decrease	(Kutawa *et al.*, 2018)
Mucor	Decrease	(Oladele, 2019)
Aspergillus	Decrease	(Yoshida *et al.*, 1987)
Botrytis cinerea	Decrease	(Lanzotti *et al.*, 2012)
Trichoderma harzianum	Decrease	(Lanzotti *et al.*, 2012)
Penicillium expansum	Decrease	(Daniel *et al.*, 2015)
Neofabraea alba	Decrease	(Daniel *et al.*, 2015)
Phomopsis sp.	Decrease	(Sittisart *et al.*, 2017)

Table 5: Outcome of garlic application on different virus

Virus name	Effect	References
Common cold virus	Decrease	(Josling, 2001)
Coxsackie Bl virus	No effect	(Tsai *et al.*, 1985)
Cytomegalovirus	Decrease	(Guo *et al.*, 1993)
Dengue virus	Decrease	(Hall *et al.*, 2017)
Herpes simplex 1	Decrease	(Tsai *et al.*, 1985)
Herpes simplex 2	Decrease	(Weber *et al.*, 1992)
HIV	Decrease	(Shoji *et al.*, 1993; Tatarintsev *et al.*, 1992)
Influenza A virus	Decrease	(Fenwick and Hanley, 1985)
Influenza B virus	Decrease	(Fenwick and Hanley, 1985)
Parainfluenza virus	Decrease	(Weber *et al.*, 1992)
Rhinovirus	Decrease	(Weber *et al.*, 1992)
Vaccinia virus	Decrease	(Weber *et al.*, 1992)
Vesicular stomatitis virus	Decrease	(Weber *et al.*, 1992)

Garlic has been proved to be inhibitory for fungal growth in many other research studies (Kutawa *et al.*, 2018) (Oladele, 2019). Table 4 summarizes the outcome of various experimental studies related to the influence of garlic application on fungi.

It is interesting to note that garlic can considerably inhibit physiological processes like respiration in fungi (Szymona, 1952). Garlic treatment was found to affect attachment mechanism of *Candida albicans* on buccal epithelial cells (Ghannoum, 1990). Some authors believe that garlic reduces fungal growth by altering the process of genetic material formation in fungal cells (Adetumbi *et al.*, 1986). Moreover, chemicals present in garlic have efficacy to destroy entire cell membrane and therefore disrupt fungal cell structure (Ghannoum, 1988). This unique characteristic of garlic to destroy fungal structure is often correlated with chemical allicin present in it (Hughes and Lawson, 1991). However, another chemical of garlic also shows the ability to reduce the growth of specific fungi. For example, garlic has diallyl trisulfide, which was observed to inhibit the growth of *Cryptococcus neoformans* (Cai, 1991). Similarly, chemical ajoene, present in garlic clove, was noted to be lethal against *Aspergillus* (Yoshida *et al.*, 1987).

Efficacy of garlic as an anti-viral agent

Apart from antibacterial action, garlic is also known for its antiviral properties. However, the research studies published in this direction are very less. Garlic extract has been observed to reduce symptoms of the influenza virus (Fenwick and Hanley, 1985). Similarly, scientists have also observed a considerable reduction in infection of cytomegalovirus after garlic intake (Meng *et al.*, 1993). Multiplication of this virus was inhibited to a maximum extent when garlic was used continuously for prolonged time period (Guo *et al.*, 1993). Garlic extract was observed to be strongly antiviral against herpes simplex virus 1 (Tsai *et al.*, 1985). However, garlic addition was observed to show no effect on virulence of Coxsackie Bl virus (Tsai *et al.*, 1985). Application of fresh garlic extract was observed to be virucidal for herpes simplex virus type 1, herpes simplex virus type 2, parainfluenza virus type 3, vaccinia virus, vesicular stomatitis virus, and human rhinovirus type 2 (Weber *et al.*, 1992). Garlic was studied to analyze its potential in preventing infection of common cold virus (Josling, 2001). In this study, 146 participants who consumed garlic supplement daily for three months faced fewer days of common cold illness (Josling, 2001). Table 5 indicates that garlic extract has immense potential to be utilized as antivirulent agent.

The antiviral property of garlic is attributed to various organosulfur compounds present in garlic bulb (Hughes *et al.*, 1989). (Weber *et al.*, 1992) reported that the presence of allicin, ajoene, methyl allyl thiosulfinate and allyl methyl thiosulfinate in garlic is responsible for imparting antivirulent property in garlic. Chemical like Ajoene, allyl alcohol and diallyl disulfide have observed to be responsible for the efficacy of garlic in diminishing HIV infection (Shoji *et al.*, 1993). Reduction in virulence of HIV in the presence of garlic was also observed by (Tatarintsev *et al.*, 1992). Recently, chemical like diallyl disulfide and alliin present in garlic have been witnessed to reduce swelling during dengue virus infection (Hall *et al.*, 2017).

CONCLUSIONS

The present review highlight that garlic is an extremely important source of organosulfur compounds. These compounds play a key role in imparting medicinal value to garlic. Application of garlic has been observed to inhibit the growth of bacteria. The organosulfur compounds like allicin are associated with antimicrobial action of garlic. Garlic also has potential to reduce fungal growth. Usage of garlic can strongly inhibit the growth of fungi like *Candida, Cyrptococcus, Rhodotorula, Fusarium* etc. Apart from inhibiting bacteria and fungi, garlic use can be effective against parasite like *Ascaridia galli, Schistosoma mansoni* etc. It is also known as a potent anti-virulent agent. Thus garlic can be considered as a sustainable natural source for reducing microbial infection. Usage of natural source like garlic would also reduce our dependence on chemical drugs in future.

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