International Journal of Current Pharmaceutical Research

ISSN- 0975-7066 Vol 18, Issue 3, 2026

Review Article

# ANTIFUNGAL EVALUATION OF EUGENOL AND GINGEROL AGAINST ASPERGILLUS NIGER: A PHYTOPHARMACEUTICAL PERSPECTIVE

**MINAL MENDHULE, LAXMIKANT KAMDE, ANMOL DHAWANDE***

**GH Raisoni University, Saikheda, Pandhurna-480334, Madhya Pradesh, India**
***Corresponding author: Anmol Dhawande; *Email: anmol.dhawande@gmail.com**

*Received: 20 Jan 2026, Revised and Accepted: 10 Mar 2026*

**ABSTRACT**

The prevalence of fungal infections is on the rise in clinical, agronomic and ecological environments, and Aspergillus niger has been found to be a highly tenacious and adaptive pathogen. The traditional antifungal agents are limited to such an extent by their toxicity, development of resistance to action, and lack of availability thus prompting the need to find safer plant-based antifungal agents. The current study examines the antifungal effect of eugenol and gingerol, which are bioactive substances extracted out of Ocimum tenuiflorum (tulsi) and Zingiber officinale (ginger), respectively. Eugenol has its antifungal effects by causing oxidative stress and cell membrane damage, whereas gingerol has a broad-spectrum effect because it inhibits biofilm formation, affects ergosterol biosynthesis, and induces cellular stress. Together, the compounds treatise has the potential to be used as dual-purpose agents in combination with antifungal approaches. Additionally, A. niger also plays an important role in industrial activities, especially in production of citric acid and green nanoparticles, thus supporting the concept of sustainable production. These review highlights the ecological flexibility of A. niger and how it could be used in ecological detoxification and the farming setting. Its findings support the use of eugenol and gingerol, not only to treat disorders but also to be used as components of environmentally friendly technologies. They are viable as future antifungal development thanks to their low toxicity, versatile modes of action, and applicability in the context of phytopharmaceutical development. The study will help to connect the traditional knowledge of plants with the modern medical and environmental requirements by introducing a holistic paradigm of fungal management.

**Keywords:** *Aspergillus niger*, Eugenol, Gingerol, Antifungal activity, Zone of inhibition, Fungal management

© 2026 The Authors. Published by Innovare Academic Sciences Pvt Ltd. This is an open access article under the CC BY license (https://creativecommons.org/licenses/by/4.0/)
DOI: https://dx.doi.org/10.22159/ijcpr.2026v18i3.9034 Journal homepage: https://innovareacademics.in/journals/index.php/ijcpr

## INTRODUCTION

The Aspergillus genus contains filamentous fungi which grow naturally in different environments while living as saprophytes within the Ascomycota fungal group. Airborne spores from these organisms spread throughout the atmosphere, which allows human beings to breathe them in. The body experiences different effects after infection because immune system health determines whether the infection will stay harmless or develop into a dangerous invasive disease [1]. Aspergillus species create various health problems which impact human wellness. These fungi trigger hypersensitivity disorders, which include allergic fungal sinusitis and allergic bronchopulmonary aspergillosis. The fungi cause chronic lung infections, which include pulmonary aspergillosis and they affect both skin and surface tissues, creating conditions that include nail infections (subungual onychomycosis) and ear infections (otomycosis) [1]. Scientists have discovered through recent research that fungal diseases now cause more than three million fatalities worldwide every year, which exceeds previous estimates of two million deaths annually. Nearly 68% which is around 2.5 million deaths are caused by invasive or serious fungal infections, showing how big of a challenge they are to global health [2]. Humans often come into contact with airborne opportunistic fungi like aspergillus, cryptococcus, and peneumpcystis, which can lead to infections. The polymorphic fungus Candida albicans which lives as a normal part of human microbiota causes severe fungal infections when the immune system becomes suppressed or unbalanced [3]. The medical field maintains a limited selection of antifungal treatments at present because existing options present dangerous side effects and rising drug resistance and expensive costs. The healthcare systems experience major stress because of these restrictions which makes it harder to control fungal infections [2]. Fungal infections create major problems for agriculture because they destroy crop plants which leads to lower food production and worsens worldwide food shortages. Fungal pathogens play a crucial role in veterinary and medical fields as well as agricultural operations. Animals experience major health problems and decreased productivity and mortality because of these diseases which produce various human illnesses that range from mild infections to deadly conditions. The various effects demonstrate how fungal pathogens create extensive damage to both the environment and the economy which requires urgent attention to protect worldwide health and food security [4]. Drug-resistant fungal pathogens have become more common which makes standard antifungal treatments less effective so patients now have fewer treatment choices. The situation demands immediate development of new therapeutic solutions which must combine safety with high treatment efficacy. Scientists now study phytopharmaceuticals, which are plant-based active compounds that show biological activity. The molecules contain various chemical structures which scientist study to find new antifungal medicines [5]. Eugenol exists as a natural aromatic substance which originates from clove oil and has been used in traditional healing practices, while scientists now study its potent antifungal properties. Studies reveal that the treatment works against multiple fungal pathogens which include Aspergillus niger. Research shows that eugenol and citral produce a strong combined effect against Aspergillus niger according to scientific studies which suggests these substances could serve as natural preservatives and combination therapy agents [6]. Gingerol together with 6-gingerol stands as the principal active component which produces the characteristic spicy taste of ginger (Zingiber officinale) and delivers multiple medicinal advantages. The plant has attracted major scientific attention because scientists want to understand its various medicinal properties which extend past its historical use as a spice and herbal treatment. The plant produces three main compounds, which show strong anti-inflammatory effects and antioxidant properties and fight against numerous harmful bacteria. The wide-ranging medicinal properties of gingerol make it a valuable natural substance which shows great promise for disease prevention and medical treatment development [7].

### Aspergillus niger: Pathogenic and industrial significance

Ecology Aspergillus niger exists throughout the world as a normal component of various environmental habitats. Aspergillus niger is a filamentous fungus that thrives aerobically on organic matter and is frequently found in soil, compost, litter, and decaying plant material.

Research demonstrates this organism survives between 6 and 47 °C while showing its best development at temperatures between 35 and 37 °C. The organism shows tolerance to pH values which range between 1.4 and 9.8 and needs at least 0.88 water activity to thrive. The fungus produces large amounts of airborne conidiospores which enables its survival in warm humid areas [8]. The genus Aspergillus is a globally distributed group of fungi with over 340 recognized species. It plays critical roles in ecosystems, agriculture, biotechnology, and human health [8]. The Aspergillus species exist as silent survivors that flourish in environments that extend from severe to hallowed territories. These organisms exist without regard for environmental elements which include temperature ranges and ground surfaces and time of year. The organisms adjust to their environment through persistence which leads them to continue participating in natural decay cycles.

- **Deserts**: Aspergillus niger together with Aspergillus flavus and Aspergillus terreus thrive in dry desert soils because they survive intense heat and limited water availability through their persistent nature.

- **Salt marshes**: The salt marshes contain Halotolerant species which include Aspergillus sydowii and Aspergillus candidus that survive saline conditions through their biochemical mechanisms to handle osmotic stress.

- **Polar regions**: Aspergillus flavus and Aspergillus niger exist as mesophilic organisms yet scientists have discovered their presence in Arctic and Antarctic soil samples which shows that microbes survive in freezing environments.

- **Agricultural fields**: The fungus Aspergillus serves two functions in this environment because it creates dangerous aflatoxin mycotoxins that harm plants but it also helps break down organic matter in the soil. A. fumigatus and A. versicolor are especially widespread.

- **Water-linked habitats**: Aspergillus sydowii functions as a sea fan pathogen across freshwater to marine and brackish water environments while maintaining its role in aquatic microbial communities.

- **Mangroves and living biota:** Aspergillus, which relies on plants as endophytes, synthesize pharmacological agents and nanoparticles with tremendous potential in the medical field that can be harnessed in the future.

- **Dust and air:** A. versicolor and A. fumigatus spread indoors into the air, which is invisible, and can be considered an insidious common allergen that can influence respiratory health.

- **Rotting wood and mummies:** These fungi decay wood and have even been seen in ancient showing their two aspects of contribution to natural decay as well to historical integrity.

- **Stones and fossiles:** Micro life forms erode the stone and aspergillus has also been detected in ancient tree resins, which is some evidence of how life has persevered over the times [9].

**Industrial use**

In the year 1919, Aspergillus niger was given a large dose of popularity since scientists chose to utilize it to produce citric acid through fermentation. Today, however, citric acid remains the giant in the marketplace out of this mould in comparison with other delicacies such as gluconic acid in relation to commercial value. It is the all-purpose souring agent of a plethora of foods and beverages-consider soft drinks, fruit juices, jam, jellies, candies, as well as wines. It appears outside the kitchen in the pharmacy world where iron citrate is used as a supplement, and even citric acid is used to preserve stored blood. We observe in the beauty industry that it controls the pH levels and prevents degradation of formulas. In industrial front, it is involved in the production of soap, leather processing, metal cleaning, etc., binding away the undesired impurities and adjusting the acidity. Nearly all commercially prepared batches of citric acid contain either A. niger or A. wentii due to the fact that these two fungi are highly beneficial in the production of high quantities of citric acid with little or no residues. The FDA of the U. S has gone to an extent of giving A. niger a green light as a harmless source of citric acid production [8].

**Immune response to aspergillus fumigates spores**

Aspergillus fumigatus is, therefore, this sporing mold. They are breaths of animals, of which we are. Our immune system eliminates an enormous amount of spores per day, and therefore people are healthy. However, in individuals who have a lesser immunity the spores remain in their body and grow to form hyphae and infect blood vessels, spreading to other parts of the body, causing severe infections. In order to explore the reaction of our body to spores in details, researchers examined mouse lungs. They observed that premature germination also known as swelling causes a surge of immune cells into the bronchi. To this end, the lung cells came into contact with large spores and secrete a bunch of signals which cause even more cells to be attracted in the process of swelling. More experiments revealed that swelling reveals some surface molecules on spores-hooks, which are absent on normal human cells. These activate the dectin 1 receptor and initiate gene expression, which promotes swelling. Combined, the facts indicate that our lungs are capable of differentiating between harmless, non-inflamed spores and perilous, swollen spores and reacting promptly in order to create a defense [9].

**Contribution of aspergillus fumigates in food products**

Aspergillus types are everywhere the world over and they are frequent in raw materials used in food and beverage preparation. These fungi are able to contaminate commodities at numerous points along the make chain, starting with the field and continuing down to post-get care. During the grow stage, the A. fumigatus can contaminate products through soil, plant fragments, or air spores. Post-get, the subsequent treatments, such as dry, brew, and store provide more opportunities of fungal growth, especially when the wetness is high and heat checks are defective. It is important to inform a portion taint beginning by growth of crops of that tied to bad store, as each of them contributes to fungi load and likelihood of azole bits [10]. Grain crops can be contaminated with bad mold, such as Aspergillus types. This leads to bad toxins. These toxins are big risks. Not only to food safety and crop value, But to the health of human beings and beasts as well [11].

**Thematic review**

**Agricultural applications**

Zinc mix (ZnO) and the silver bits (AgNPs) that Aspergillus niger produces are rather useful in crop growth. They increase seed germination and root growth in such crops as wheat and rice. They enhance the immunity of the plants against germs. They provide important needs of micronutrients besides being germ-killing agents. These bits save on the use of chemical feeds and kill mixes and this ends up making the soil healthy [12].

These morsels may be prepared in a green manner. Their manufacturing requires little power and they do not have any bad leftovers, which fits the green vibe perfectly. In fungi the stuff is very large that cuts down nits. They cut metal pieces and in this way, fungi are more appropriate and efficient than germ techniques [13].

**Biomedical applications**

These silver-gold nanoparticles (Ag-AuNPs) are quite impressive at bursting and preventing clots as well as produced by Aspergillus niger. They also induce death to cancer cells such as the HepG2 and the A549 cells, by snacking the cells into death and increasing cellular stress [14]. Aspergillus flavus preparations of se-NPs are hyper effective in eliminating odious bacteria and against hard biofilms. They are safe to apply and yield clean outcomes thus these minute particles appear to a resolute step of fresh treatment methods [15].

**Environmental applications**

The minute components of fungi are useful in cleaning the earth. They contribute to the water clean-up, reduce the amount of bad metals, and purify the air. Silver bits produced by a fungus aspergillus niger kill germs in water, among other things. In addition, zinc bits and titanium bits disintegrate bad air stuff [16].

It is a scalable and sustainable process of production that does not depend on the usage of harmful chemicals or energy wastefulness, which can contribute to the ecological restoration [12].

**Phytopharmaceuticals in antifungal therapy**

Phyto-aid (plant-based products) are getting a lot of interest as substitutes of conventional antifungal drugs. They contain flavonoid, terpenoid, alkaloid, and essential oils that disrupt fungal cell walls, prevent growth processes, and block biofilm formation as well as subject the fungus to stress thus killing it. In the combination with synthetic antifungals, they will be greener and more environmentally friendly, and such a mixture can be used both medically and in the field in the long run. Nevertheless, we have difficulties like differences in species of plants, low water solubility and the reduced practical performance. The emergence of new formulation and delivery technologies might render phyto-aid one of the major elements of the antifungal approach in the future. Due to the increase in infections caused by Candida, new treatment researches are speeding up. There are a number of classes of antifungal drugs-polyenes, azoles, allylamines, echinocandins and the pyrimidines. The most useful and commonly used against candidiasis are polyenes, azoles, echinocandins as well as pyrimidines [17]. Antifungal drugs can be developed but with some severe challenges. A major problem is the fast development of drug-resistant fungi such as Candida and Aspergillus; the common drugs do not work against them. Most treatments are also associated with serious side effects-such as amphotericin B that is known to destroy kidneys and cause other toxicity. Moreover, there are not many antifungal classes and new classes are not very numerous. Due to the numerous similarities between fungi and human cells, it is difficult to create medications that will eliminate fungi and at the same time not harm the patients. Other fungi are present in biofilms on surfaces and in tissues and medical equipment, protecting them against drugs and the immune system. The effectiveness of drugs is reduced by delivery issues, including the lack of solubility, poor tissue penetration and rapid degradation. Lastly, antifungal treatments are very expensive and long-lasting, which places an additional burden on the patients and the health care sector.

**Mechanisms of action**

Like any other natural extract, pest-killing activity of essential oils (EOs) is conditional upon their structure and the percentage of each component. There are antimicrobial ingredients that are continuously produced by the plants and those whose synthesis depends on the attack of the plant on harmful insects. The vegetables, spices, and fruits that contain EOs are good commodities that are effective, naturally resistant and prevent the small pests that pose a danger to our well-being and the agriculture sector [18]. Biofilm break-up is a hard, step-by-step act. It has the fall of the outer gel and changes in cell feel. This lets cells live on their own. For lots of germ types, this break-up mainly comes from the throw of outer stuff. These can break down and melt the things that hold the gel tight. As the gel breaks up, the cells let go andmove to places near them [19].

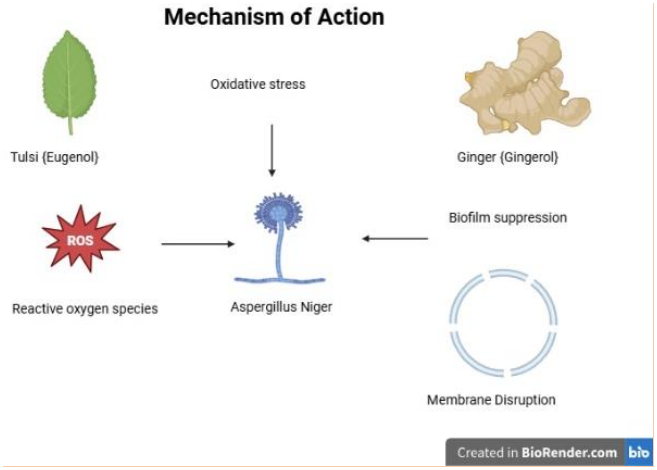


**Fig. 1: Proposed mechanism of antifungal action of Tulsi and ginger constituents against Aspergillus niger. Created with BioRender.com [20]**

**LIMITATIONS**

The wild gives us a big gift box. The set of stuff that can work is not all there. Take, for instance, the vast mix of anti-fungal substances in sea life and small life forms. Some bits can stop biofilm. This text sums up the main worth of active block. But it does not show the rate for biofilm stop [21].

**Plant having antifungal activity**

The use of anti-fungus drugs is on the rise. This leads to fungus that need more drugs to kill them. The rise of these tough fungi and the lack of good drugs to kill them show we must find new cures. We need to look at plants for help. In the olden days, people would fight fungus folk-way with plants. These plants provided a hand to both people and pets, which is why they are a good beginning point in the hunt against new antifungal equipment [22]. Many ancient books emphasize the use of herbs by traditional medicine. We are looking at plants that combat fungus here--and prevent those that of us make sick. Plants that possess anti-fungal properties are also discussed in the write-up.

We have been researching on the use of plant-derived compounds and it happens that they are rather effective as anti-fungal agents. Such compounds as flavonoids, terpenoids, alkaloids and phenolics do so in a variety of different ways. They are able to destroy the walls of fungal cells, prevent the formation of biofilm and block essential metabolic mechanisms. Their sources, fungal targets and mechanisms are included in the table in my notes. It actually demonstrates the way nature provides us with a toolbox. The information might be the foundation of safer and more eco-friendly antifungal measures [22].

**Eugenol: a potent phenolic antifungal**

Eugenol, comprising 70 to 85 percent of the clove oil is known to be very effective in killing fungi. It acts on a variety of species, ranging from yeasts, such as Candida to large molds, such as Aspergillus, Penicillium and Fusarium. So, eugenol may become a natural and solid antifungal reagent of health, agriculture and food conservation [23]. Experiments can explain the mechanism of what happens with eugenol by fungi: it acts on the cell wall, degrading them and causing the leakage of contents. It also prevents the manufacture of one of the essential elements of the wall, which puts an additional load on the cell. All these render it difficult to the fungus to survive and develop [24, 25]. Eugenol has several real-life applications. It is a food preservative and part of medicine. It is even reported that vaporized eugenol could stop the growth of Molds in stored grains [26]. Clove oil has the potential to prevent the growth of A. niger in laboratory tests, and it performs like oils of cinnamon, mint and thyme. In addition, the effectiveness of eugenol may also be enhanced in combination with other plant-based compounds, such as citral or menthol, so it may be a key fig. in antifungal combinations [27].

**Table 1: Plant specific phytoconstituents**

| S. No. | Plant | Plant part | Phytoconstituents |
|---|---|---|---|
| 1 | Zingiber officinale | Rhizome | Gingerol |
| 2 | Ocimum tenuiflorum | Whole plant | Eugenol |
| 3 | Datura metal | Whole plant | Alkaloids |
| 4 | Ananas comosus | Leaves | Protein |
| 5 | Cassia tora | Whole plant | Emodin |
| 6 | Pinus pinaster | Leaves | Pinosylvin |
| 7 | Smilax medica | Root | Saponins |
| 8 | Haloxylon salicorcium | Aerial plant | Alkaloids |
| 9 | Ocimum grasstissimum | Bark | Essential oil |
| 10 | Alpinia galanga | Seeds | Diterpenes |

**Gingerol: an underexplored antifungal candidate**

The primary ingredient of Zingiber officinale (ginger) gingerol has been demonstrated to be very essential to the piquant taste of the spice as well as much of its medicinal worth. Throughout the years, scientists have found out that it is not only an agent of flavor, it is a potent health-promoting substance with a wide range of therapeutic uses. Research proves that gingerol can be used to reduce inflammation, protect cells, prevent cancer, and maintain overall body functions. It is a major concern of the traditional and modern pharmacological studies [28]. Gingerol or the core of ginger is famously known to have health advantages. It inhibits pain and swelling and regulates molecules like cytokines and pathways like NF-kB and MAPK. It protects neurons, enhances learning and memory, and reduces neurodegenerative diseases to Alzheimer in the brain. Furthermore, gingerol is a powerful antioxidant, which combats the free radical-induced harm, as well as alleviates stress. It also prevents vomiting and nausea. The safety studies indicate that it is well tolerated mostly and thus it is a popular natural supplement and a useful ingredient in health foods [28]. One of the most important elements of ginger (Zingiber officinale) is gingerol which is a strong resistant against numerous dangerous elements. Tests indicate that it can reverse fungus sickness toxin and microbiological product injuries. Gingerol limits the damage caused by these toxins by alleviating cell stress, oxidative damage, and cell wall maintenance. Its protective effect shows that it has a potential of being an effective natural remedy to infections brought about by pathogens in humans and animals [29].

**CONCLUSION**

The increasing risk of fungal infections in health, agriculture, and ecosystem urging the development of safer and more sustainable antifungal agents. This paper brings into focus the potential of two promising compounds; eugenol from clove and gingerol from ginger and their effectiveness against Aspergillus niger. Themode of action of both compounds work by disrupting the fungal cell wall and triggering oxidative stress, hence proving their strong and adaptable antifungal capabilities. These plant-derived compounds are more appealing as they not only exhibit medicinal properties but, serve as eco-friendly alternatives to synthetic chemicals, finding practical use in preserving food, developing biomedical products, and managing unwanted plant growth in agriculture. Interestingly enough, Aspergillus niger is also associated with green nanotechnology as it biosynthesizes bioactive particles and it is essential to emphasize that fungi are both pathogens and biotechnological partners.

Finally, eugenol and gingerol are a step towards an antifungal approach based on nature. If these incorporated into phytopharmaceuticals would literally open the door to some holistic and low-toxicity and would completely be consistent with the global sustainability principles.

**FUNDING**

Nil

**AUTHORS CONTRIBUTIONS**

All authors have contributed equally

**CONFLICT OF INTERESTS**

Declared none

**REFERENCES**

1. Mancianti F, Ebani VV. Biological activity of essential oils. Molecules. 2020;25(3):678. doi: 10.3390/molecules25030678, PMID 32033336.
2. Souza CM, Bezerra BT, Mellon DA, De Oliveira HC. The evolution of antifungal therapy: traditional agents, current challenges and future perspectives. Current Research in Microbial Sciences. 2025;8:100341. doi: 10.1016/j.crmicr.2025.100341.
3. Palmieri F, Koutsokera A, Bernasconi E, Junier P, Von Garnier C, Ubags N. Recent advances in fungal infections: from lung ecology to therapeutic strategies with a focus on Aspergillus spp. Front Med (Lausanne). 2022;9:832510. doi: 10.3389/fmed.2022.832510, PMID 35386908.
4. Tan LF, Yap VL, Rajagopal M, Wiart C, Selvaraja M, Leong MY. Plant as an alternative source of antifungals against Aspergillus infections: a review. Plants (Basel). 2022;11(22):3009. doi: 10.3390/plants11223009, PMID 36432738.
5. Kumar Mishra KK, Deep Kaur C, Kumar Sahu A, Panik R, Kashyap P, Prasad Mishra S. Medicinal plants having antifungal properties. In: Abdul Rasool Hassan B, editor. Medicinal plants use in prevention and treatment of diseases. IntechOpen; 2020. doi: 10.5772/intechopen.90674.
6. Salem MZ, Abo-Elgat WA, Mansour MM, Selim S. Antifungal activity of the monoterpenes carvacrol p-cymene eugenol and iso-eugenol when applied to wood against Aspergillus flavus Aspergillus niger, and Fusarium culmorum. BioResources. 2024;20(1):393-412. doi: 10.15376/biores.20.1.393-412.
7. Mao QQ, Xu XY, Cao SY, Gan RY, Corke H, Beta T. Bioactive compounds and bioactivities of ginger (Zingiber officinale Roscoe). Foods. 2019;8(6):185. doi: 10.3390/foods8060185, PMID 31151279.
8. Schuster E, Dunn Coleman N, Frisvad JC, Van Dijck PW. On the safety of Aspergillus niger a review. Appl Microbiol Biotechnol. 2002;59(4-5):426-35. doi: 10.1007/s00253-002-1032-6, PMID 12172605.
9. Hohl TM, Van Epps HL, Rivera A, Morgan LA, Chen PL, Feldmesser M. Aspergillus fumigatus triggers inflammatory responses by stage-specific beta-glucan display. PLOS Pathog. 2005;1(3):e30. doi: 10.1371/journal.ppat.0010030, PMID 16304610.
10. Castro Rios K, Buri MC, Ramalho Da Cruz AD, Ceresini PC. *Aspergillus fumigatus* in the food production chain and azole resistance: a growing concern for consumers. J Fungi (Basel). 2025;11(4):252. doi: 10.3390/jof11040252, PMID 40278073.
11. Tashiro M, Nakano Y, Shirahige T, Kakiuchi S, Fujita A, Tanaka T. Comprehensive review of environmental surveillance for azole-resistant *Aspergillus fumigatus*: a practical roadmap for hospital clinicians and infection control teams. J Fungi (Basel). 2025;11(2):96. doi: 10.3390/jof11020096, PMID 39997390.
12. Rai M, Gupta I, Bonde S, Ingle P, Shende S, Gaikwad S. Industrial applications of nanomaterials produced from *Aspergillus* species. In: Razzaghi-Abyaneh M, Rai M, editors. The genus aspergillus pathogenicity mycotoxin production and industrial applications. IntechOpen; 2022. doi: 10.5772/intechopen.98780.
13. Irshad MA, Hussain A, Nasim I, Nawaz R, Al-Mutairi AA, Azeem S. Exploring the antifungal activities of green nanoparticles for sustainable agriculture: a research update. Chem Biol Technol Agric. 2024;11(1):62. doi: 10.1186/s40538-024-00662-1.
14. Abu-Tahon MA, Alshammari FA, Shahhat IM, Ghareib M, Abdallah WE. Eco-friendly synthesis, characterization and biomedical applications of biosynthesized bimetallic silver-gold

nanoparticles by culture supernatant of *Aspergillus niger*. Appl Biochem Biotechnol. 2025;197(1):137-58. doi: 10.1007/s12010-024-05035-w, PMID 39106026.

15. Mohammed EJ, Abdelaziz AE, Mekky AE, Mahmoud NN, Sharaf M, Al-Habibi MM. Biomedical promise of *Aspergillus flavus*-biosynthesized selenium nanoparticles: a green synthesis approach to antiviral anticancer, anti-biofilm and antibacterial applications. Pharmaceuticals (Basel). 2024;17(7):915. doi: 10.3390/ph17070915, PMID 39065765.
16. Gaikwad Sagar, Bhosale Ashok. Green synthesis of silver nanoparticles using *Aspergillus niger* and its efficacy against human pathogens. Pelagia Res Libr. 2012;2(5):1654-8.
17. Dantas TD, Machado JC, Ferreira MR, Soares LA. Bioactive plant compounds as alternatives against antifungal resistance in the Candida strains. Pharmaceutics. 2025;17(6):687. doi: 10.3390/pharmaceutics17060687, PMID 40574000.
18. Nazzaro F, Fratianni F, De Martino L, Coppola R, De Feo V. Effect of essential oils on pathogenic bacteria. Pharmaceuticals (Basel). 2013;6(12):1451-74. doi: 10.3390/ph6121451, PMID 24287491.
19. Roy R, Tiwari M, Donelli G, Tiwari V. Strategies for combating bacterial biofilms: a focus on anti-biofilm agents and their mechanisms of action. Virulence. 2018;9(1):522-54. doi: 10.1080/21505594.2017.1313372, PMID 28362216.
20. BioRender. BioRender–online tool for scientific figure creation; 2025. Available from: https://www.biorender.com. [Last accessed on 30 Apr 2026].
21. Zhang CW, Zhong XJ, Zhao YS, Rajoka MS, Hashmi MH, Zhai P. Antifungal natural products and their derivatives: a review of their activity and mechanism of actions. Pharmacological Research Modern Chinese Medicine. 2023;7:100262. doi: 10.1016/j.prmcm.2023.100262.
22. Faruki SR, Gayke SD, Nikam SM, Bornare RK, Dube SB. Medicinal plants having antifungal property. Int J Pharm Res Appl. 2023;8(1):1397–401. doi: 10.35629/7781-080613971403.
23. Tyagi AK, Malik A. Liquid and vapour-phase antifungal activities of selected essential oils against Candida albicans: microscopic observations and chemical characterization of Cymbopogon citratus. BMC Complement Altern Med. 2010;10:65. doi: 10.1186/1472-6882-10-65, PMID 21067604.
24. Chaieb K, Zmantar T, Ksouri R, Hajlaoui H, Mahdouani K, Abdelly C. Antioxidant properties of the essential oil of Eugenia caryophyllata and its antifungal activity against a large number of clinical Candida species. Mycoses. 2007;50(5):403-6. doi: 10.1111/j.1439-0507.2007.01391.x, PMID 17714361.
25. Marchese A, Barbieri R, Coppo E, Orhan IE, Daglia M, Nabavi SF. Antimicrobial activity of eugenol and essential oils containing eugenol: a mechanistic viewpoint. Crit Rev Microbiol. 2017;43(6):668-89. doi: 10.1080/1040841X.2017.1295225, PMID 28346030.
26. Kedia A, Prakash B, Mishra PK, Dubey NK. Antifungal and antiaflatoxigenic properties of Cuminum cyminum (L.) seed essential oil and its efficacy as a preservative in stored commodities. Int J Food Microbiol. 2014;168-169:1-7. doi: 10.1016/j.ijfoodmicro.2013.10.008, PMID 24211773.
27. Ju J, Xie Y, Yu H, Guo Y, Cheng Y, Zhang R. Synergistic inhibition effect of citral and eugenol against Aspergillus niger and their application in bread preservation. Food Chem. 2020;310:125974. doi: 10.1016/j.foodchem.2019.125974, PMID 31835216.
28. Promdam N, Panichayupakaranant P. "[6]-Gingerol: a narrative review of its beneficial effect on human health." Food Chemistry Advances. 2022 Oct;1:100043. doi: 10.1016/j.focha.2022.100043.
29. Yahyazadeh R, Baradaran Rahimi V, Yahyazadeh A, Mohajeri SA, Askari VR. Promising effects of gingerol against toxins: a review article. Biofactors. 2021;47(6):885-913. doi: 10.1002/biof.1779, PMID 34418196.