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POPULAR ARTICLE

## Fungi: Benefactors, Pathogens and Biotechnological Frontiers

**Dr. Tanmay Shukla, Dr. Vinay Kumar**

MVSc Scholar,

Department of Veterinary Public Health and Epidemiology,  
DUVASU, Mathura

\*Corresponding Author: [tanmayshukla20016@gmail.com](mailto:tanmayshukla20016@gmail.com)

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### Abstract:

Fungi are vital to life on Earth; they act as decomposers, nutrient recyclers, and plant partners that sustain nearly 90% of plant species. They are invaluable in medicine, agriculture, and industry, producing drugs like penicillin and statins, serving as natural biocontrol agents such as *Trichoderma* and *Beauveria bassiana*, and driving fermentation, enzyme, and organic acid production. However, fungi also pose serious threats: pathogenic species like *Candida* and *Aspergillus* cause infections, while mycotoxins contaminate food and feed. Despite these hazards, fungi contribute over USD 54 trillion annually to global ecological and industrial systems, emphasizing their dual role as both benefactors and biohazards crucial to one's health and planetary sustainability.

**Keywords:** Fungi, Antibiotics, Antifungal resistance, Mycoses, Mycotoxins and One Health

### Introduction:

Fungi are some of the most fascinating and versatile organisms on our planet. They can exist as single microscopic cells, like yeast, or as large, complex forms, such as mushrooms in forests. Found almost everywhere – from soil and plants to air and even inside our bodies – fungi play crucial roles in ecosystems, industry, and human health. Though they may look like plants, fungi are closer relatives of animals. Unlike plants, they cannot make their own food through photosynthesis. Instead, fungi grow on or within their food sources, releasing enzymes that break down organic matter and absorb nutrients. This unique way of living makes them nature's best recyclers. Fungi stand at the crossroads of health and hazard - powering medicine and industry on one side, while challenging global health and food safety on the other.

### The Good Side of Fungi:

Not all fungi are harmful - many plays vital roles in sustaining life on Earth and enriching our everyday lives. Fungi are powerful decomposers, breaking down dead plants and animals to recycle nutrients back into the soil. They also form partnerships with plants through structures called mycorrhizae, helping roots absorb water and minerals. In fact, about 90% of plants depend on these fungal

allies to survive. Several significant applications of fungi are discussed below:

### 1. Role of Fungi in Medicine and Health:

Fungi synthesize numerous natural products (NPs) with antimicrobial, anticancer, antidiabetic, and immunomodulatory activities. Key compounds include penicillin (*Penicillium rubens*), cephalosporin C (*Acremonium chrysogenum*), and cyclosporin A (*Tolypocladium niveum*). Fungal metabolites also combat ESKAPE pathogens-major multidrug-resistant species.

Table below lists antifungal and antibacterial agents like griseofulvin, gliotoxin, echinocandin B, lovastatin, and beauvericin, underlining fungi's central role in modern pharmacology.

Antimicrobial Agent	Producing Fungus	Active Against / Biological Activity
<b>Mycophenolic acid</b>	<i>Penicillium brevicompactum</i>	Broad antibacterial, antifungal, antiviral, antitumor, and immunosuppressive activity
<b>Penicillin</b>	<i>Penicillium notatum</i>	Staphylococcus aureus
<b>Penicillin G</b>	<i>Penicillium rubens</i>	Streptococcus, Staphylococcus, Enterococcus, Clostridium, Treponema spp
<b>Cephalosporin C</b>	<i>Acremonium chrysogenum</i>	Broad-spectrum antibacterial activity
<b>Amatoxin, Phallotoxin</b>	Amanita spp.	Cytotoxic and anticancer effects
<b>Ustilotoxin</b>	<i>Ustilaginoidea virens</i>	Cytotoxicity against various cancer cell lines
<b>Beauvericin (A- H)</b>	Fusarium, Alternaria, Calonectria, Cordyceps, Ophiocordyceps spp	Antimicrobial and insecticidal activity
<b>Roquefortine C</b>	<i>Penicillium roqueforti</i>	Toxic to mammals (mice and dogs); antimicrobial potential
<b>Gliotoxin</b>	<i>Aspergillus fumigatus</i>	Antifungal activity against <i>Candida albicans</i> and <i>Aspergillus</i> spp.
<b>Griseofulvin</b>	<i>Penicillium griseofulvum</i>	Antifungal against dermatophytes; also used for skin infections in humans and animals
<b>Patulin</b>	<i>Aspergillus clavatus</i>	Fungistatic activity against <i>Rhizoctonia solani</i> , <i>Botrytis cinerea</i> , <i>Fusarium oxysporum</i>
<b>Rubellins (anthraquinones)</b>	<i>Ramularia collo-cygni</i>	Antimicrobial and cytotoxic activity against <i>Bacillus subtilis</i> , <i>S. aureus</i> , and <i>Enterococcus faecalis</i> .
<b>Viriditoxin</b>	<i>Penicillium radicum</i>	Active against methicillin-resistant <i>S. aureus</i> (MRSA)
<b>Lindgomycin</b>	Lindgomycetaceae family	Active against Gram-positive bacteria and <i>Candida albicans</i>
<b>Echinocandin B</b>	<i>Aspergillus nidulans</i>	Antifungal activity against <i>Candida</i> spp.
<b>Caspofungin</b>	<i>Glarea lozoyensis</i>	Antifungal against <i>Candida</i> spp. and <i>Aspergillus</i> spp.

<b>Aureobasidin A</b>	<i>Aureobasidium pullulans</i>	Fungicidal against <i>Candida</i> spp., <i>Cryptococcus neoformans</i> , <i>Blastomyces dermatitidis</i> , <i>Histoplasma capsulatum</i>
<b>Aspergillomarasmine A</b>	<i>Aspergillus versicolor</i>	Active against Gram-negative bacteria; inhibits $\beta$ -lactamases
<b>Cyclosporin A</b>	<i>Tolypocladium niveum</i>	Immunosuppressive and antiviral (anti-coronavirus) activity
<b>Peptaibols</b>	<i>Trichoderma reesei</i>	Antifungal against <i>Alternaria alternata</i> , <i>Phoma cucurbitacearum</i> , <i>Fusarium</i> spp
<b>Enfumafungin</b>	<i>Hormonema</i> spp	Antifungal activity against <i>Cryptococcus neoformans</i> and <i>A. fumigatus</i>
<b>Lovastatin</b>	<i>Aspergillus terreus</i>	Used for hypercholesterolemia treatment
<b>Mevastatin</b>	<i>Penicillium citrinum</i>	Cholesterol-lowering compound
<b>Clavatul</b>	<i>Aspergillus clavatus</i> , <i>A. clavatonanicus</i>	Fungistatic activity against <i>C. albicans</i> , <i>A. niger</i> , and <i>F. oxysporum</i>
<b>Pyranonigrins (A-F)</b>	<i>Aspergillus niger</i> , <i>Penicillium brocae</i>	Broad-spectrum antibacterial activity

## 2. Role of Fungi in Agriculture:

Fungi like *Trichoderma* and entomopathogens such as *Beauveria bassiana* and *Metarhizium anisopliae* act as natural biocontrol agents against plant pathogens, nematodes, and insect pests. Through antibiosis, enzyme production, and competition, they promote plant growth and reduce reliance on chemical pesticides and fertilizers, fostering sustainable agriculture.

## 3. Role of Fungi in Industry and Food:

Fungi have millennia-old roles in fermentation, producing cheese (*Penicillium roqueforti*, *P. camemberti*), bread, beer, and wine (*Saccharomyces cerevisiae*), as well as fermented meats (*P. nalgiovense*). Edible mushrooms like *Agaricus bisporus*, *Pleurotus ostreatus*, *Flammulina*, and *Lentinula edodes* provide protein-rich food. Modern innovations include mycoproteins such as Quorn (*Fusarium venenatum*), a fiber-rich meat alternative. *Aspergillus oryzae* powers Asian fermentations (soy sauce, miso, sake), *Botrytis cinerea* enhances “noble rot” wines, and fungi produce organic acids, enzymes, vitamins, and pigments for industry.

## 4. Role of Fungi in Industrial Metabolites:

Fungi efficiently produce organic acids-citric, gluconic, lactic, itaconic, malic, succinic, fumaric, and oxalic acids-used in food, pharma, and chemical industries. *Aspergillus niger* dominates citric and gluconic acid production, generating over 6 million tons annually, while *A. terreus* produces itaconic acid and lovastatin. *Rhizopus* species yield pure L-lactic acid from starch-based wastes. These processes often use cheap agro-industrial residues (banana peels, molasses, apple waste), aligning with circular-economy principles.

## 5. Role of Fungi in Enzyme Production:

Filamentous fungi are major enzyme producers-Aspergillus, Penicillium, Trichoderma, Rhizopus-yielding amylases, proteases, pectinases, lipases, chitinases, cellulases, and ligninases. These enzymes underpin industries from baking, brewing, textiles, and detergents to biofuel generation and waste bioremediation. *A. niger* and *T. reesei* are leading cellulase producers, while *Thermomyces lanuginosus* generates thermostable proteases. Enzyme markets account for ~25 % of global biotechnological enzyme use.

## 6. Role of Fungi in Pigments Production:

Fungi naturally synthesize safe colorants such as polyketides, carotenoids, and melanins. *Monascus* species yield red-orange pigments used in food and cosmetics, while *Blakeslea trispora* produces  $\beta$ -carotene-a vitamin A precursor. Fungal pigments provide eco-friendly alternatives to synthetic dyes, with applications in textiles, pharmaceuticals, and skincare.

## Impact of Fungi on the Environment:

Fungi protect the environment through mycoremediation, breaking down or absorbing pollutants. *Trichoderma*, *Aspergillus*, and *Penicillium* remove heavy metals and hydrocarbons, while *Mucor irregularis* and *A. oryzae* degrade oil. Lignin-degrading enzymes (laccases, peroxidases) detoxify synthetic dyes and chemicals. Oleaginous fungi like *Mortierella isabellina* and *A. terreus* produce biodiesel, and others aid bioethanol production. Mycofiltration uses fungal mycelia to purify wastewater. Together, these roles underscore fungi's ecological and economic value in sustainability and biotechnology.

## Fungi and the Global Economy:

Recent research estimates that fungi contribute an astounding USD 54.57 trillion to the global economy. Their ecological services-such as carbon sequestration, soil fertility enhancement, and ecosystem stability-constitute the foundation of this value. Mycorrhizal fungi, in particular, help capture and store carbon in forests and soils, playing a vital role in combating climate change. Economically, fungi fuel billion-dollar industries:

- **Pharmaceuticals:** Antibiotics, statins, immuno-suppressants, and antifungal drugs.
- **Food & Beverage:** Yeasts in beer, wine, and bread; molds in cheese production.
- **Agriculture & Biotechnology:** Enzymes, biopesticides, and biofertilizers.
- **Environmental Services:** Bioremediation and carbon storage.

By recycling nutrients, producing medicines, and supporting sustainable industries, fungi are quietly powering modern civilization.

## The Hidden Dangers:

### • Fungi and Human Health:

While many fungi are beneficial, some can cause serious harm. Fungal infections-known as mycoses-affect over a billion people every year and cause around 1.5 million deaths, making them as

deadly as malaria and tuberculosis. Common fungal diseases include skin infections like ringworm (caused by *Trichophyton* and *Microsporum*) and life-threatening infections caused by fungi such as *Candida*, *Aspergillus*, *Cryptococcus*, and *Histoplasma*. *Candida* species are normally harmless inhabitants of the human body, but when immunity drops, they can cause infections ranging from vaginal yeast infections to deadly bloodstream infections. A new species, *Candida auris*, has become a global health concern due to its resistance to multiple antifungal drugs. *Aspergillus fumigatus* can trigger allergies, asthma, and invasive lung infections, particularly in patients with weakened immune systems or those recovering from flu or COVID-19. *Cryptococcus neoformans* and *C. gattii* can infect the brain, cause meningitis and leading to over 100,000 deaths annually. Dimorphic fungi, such as *Histoplasma* and *Coccidioides*, can switch between mold and yeast forms, causing serious lung diseases like histoplasmosis and Valley fever. During the COVID-19 pandemic, another deadly infection, mucormycosis (the “black fungus”), gained attention for its high fatality rate among patients with diabetes or compromised immunity. Antifungal resistance is a growing threat, largely due to the overuse of azole-based fungicides in medicine and agriculture. Scientists are now exploring new treatments, including nanotechnology, immunotherapy, and RNA-based therapies to combat resistant strains.

#### • Fungi and Animal Health:

Fungi do not just affect humans—they also pose serious risks to animals. In birds, aspergillosis (caused by *Aspergillus fumigatus*) is a leading cause of death, costing the poultry industry millions every year. Other animals like cattle, horses, dogs, and cats also suffer from fungal infections such as mucormycosis, cryptococcosis, and candidiasis. Dermatophytosis (ringworm) is the most common zoonotic fungal disease worldwide, easily spreading between animals and humans. Cats infected with *Microsporum canis* are a major source of human infection. Wildlife, too, is under threat: Amphibians are dying in large numbers from chytridiomycosis, caused by *Batrachochytrium dendrobatidis*. Bats suffer from white-nose syndrome, a deadly disease caused by *Pseudogymnoascus destructans*. Fish and reptiles are affected by fungal infections that can cause severe skin and tissue damage.

These diseases not only impact animal health but also threaten biodiversity and food security. Overuse of antifungal drugs in veterinary care has led to resistant strains, emphasizing the need for One Health approaches—linking human, animal, and environmental health.

#### • Mycotoxins in Food and Feed:

Even when fungi are not infecting living beings directly, their toxins—called mycotoxins—can still cause harm. Produced by fungi like *Aspergillus* and *Fusarium*, these toxic compounds contaminate about 25% of the world’s food and feed each year. Common mycotoxins such as aflatoxins, fumonisins, and zearalenone can cause liver damage, immune suppression, reduced

fertility, and even cancer in animals and humans. Contaminated feed leads to growth problems, reproductive failures, and death in livestock. Climate change and poor storage conditions worsen this problem by creating ideal environments for fungi to grow. Developing better detection and prevention strategies is essential to protect food safety and animal health.

### Conclusion:

Fungi represent a dual force of nature-vital for ecosystem balance, human health, and industry, yet capable of causing serious diseases and ecological harm. Their remarkable benefits in medicine, agriculture, and biotechnology highlight their immense potential, but rising antifungal resistance and environmental change demand vigilance. A balanced, One Health approach is essential to maximize their benefits while minimizing risks, ensuring fungi remain allies in a sustainable future.

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