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# Sustainable Management of Mushroom Pests and Diseases Using Plant-Derived Bioactive Products: Advances, Challenges and Future Perspectives

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**Abstract**
Mushroom production has emerged as an expanding agricultural sector because mushrooms provide essential nutritional benefits and medicinal properties and economic value in all regions of the world. The commercial production of mushrooms faces serious challenges from various insect pests, mites, nematodes, bacterial diseases, fungal infections and viral complexes which decrease the plants yield and quality and marketability. The conventional management methods use synthetic pesticides and disinfectants as their primary control tools which create multiple problems through their repeated application because it causes pesticide residues, pathogen resistance, environmental damage and health risks for consumers. The increasing demand for bioactive substances derived from plants now serves as a viable solution to replace synthetic methods used for mushroom protection. Plant extracts, essential oils, seed cakes and purified phytochemicals from *Azadirachta indica, Allium sativum, Eucalyptus globulus, Syzygium aromaticum* and *Moringa oleifera* show insecticidal, acaricidal, nematicidal, antibacterial and antifungal activities. The development of nanoformulations, essential oil encapsulation and advanced application methods has improved both stability and performance of botanical products. The review shows the latest technology breakthroughs while it studies plant-based control methods and provides an overview of existing research about key mushroom pests and diseases and it identifies present

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issues and future opportunities for using botanicals in environmentally friendly mushroom farming methods.

**Keywords:** Mushroom, Pests and Diseases, Sustainable Management, Plant-Derived Bioactive Products

## 1 Introduction

The high productivity of mushroom production combined with its short cropping cycle, efficient substrate conversion and increasing market demand for functional foods has established mushroom production as the most rapidly expanding sector within protected horticulture and circular bioeconomy (Abdelkhalek et al., 2025). Edible and medicinal mushrooms contain a wide range of nutritional elements which include high quality proteins, dietary fiber, vitamins, minerals, antioxidants, β-glucan and additional bioactive metabolites that promote human health and nutritional security (Balenzano et al., 2025). Mushroom production across the globe has experienced major growth during the last two decades with Asian countries especially China dominating the market while European, North American and tropical developing countries follow behind (Dong et al., 2025).The species *Agaricus bisporus*, *Pleurotus spp., Lentinula edodes*, *Volvariella volvacea*, *Flammulina velutipes* and lead both the commercial market and the medicinal market because they receive high consumer acceptance and generate significant economic value (Soares et al., 2026). The economic value of mushrooms extends beyond their fresh use because they are processed into powders that serve as nutraceuticals, meat substitutes, beverages and medicinal products (Malakar et al., 2025). The actual land requirement for mushroom farming is minimal because the method utilizes agricultural residues which include wheat straw, rice straw, cotton waste, sawdust and sugarcane bagasse as its growing material (Manta et al., 2025). The process of mushroom cultivation serves as an essential component for both sustainable agriculture practices and systems which convert waste materials into usable products because it enables the transformation of lignocellulosic biomass into valuable food products (Mahapatra et al., 2025). Mushroom cultivation faces numerous biotic challenges which limit its production potential despite the advantages it offers. The warm humid organic rich environments which mushrooms require for their growth enable insect pests, mites, nematodes, bacteria, competitive molds and dangerous fungus to spread throughout these areas (Dong et al., 2025). The main insect pests which transmit infections to mycelium, compost and fruiting bodies are the larvae of sciarid flies, phorid flies, springtails and beetles (Aguiar et al., 2026). Mites and nematodes cause further damage to mycelial networks and sporophore development which leads to lower production results and financial losses in the market (Manta et al., 2025). The most harmful diseases that exist worldwide include Trichoderma spp caused green mold and *Lecanicillium fungicola* caused dry bubbles, *Mycogone perniciosa* caused wet bubbles, *Cladobotryum* caused cobweb disease and *Pseudomonas tolaasii* caused bacterial blotches (Wani et al., 2025). The extent of yield losses from pests and diseases depends on factors such as pathogens, environmental conditions, hygiene practices and management efficiency (Soares et al., 2026). Intensive mushroom production systems have relied on synthetic fungicides and insecticides as well as disinfectants and fumigants for their sanitation needs and disease control requirements (Heredia-Bátiz et al., 2025). The irresponsible handling of these chemicals has created multiple serious problems which include pesticide residues that contaminate edible fruiting bodies, the development of pest, pathogen resistance, the risk of worker exposure, environmental pollution and the increasing number of regulatory restrictions across various nations (Wadhwa et al., 2024). The incorrect application of fungicidal agents can lead to negative effects on crop growth and spawn run and yield because mushrooms which are cultivated by farmers belong to the fungus category (Marčić et al., 2025). Ecofriendly mushroom agriculture has new commercial incentives as customer preferences for residue free, organically produced and environmentally sustainable foods have grown in recent years (Wadhwa et al., 2024). Crude extracts essential oils seed powders plant cakes hydrosols and purified phytochemicals which possess insecticidal repellent nematicidal antibacterial and antifungal properties have become more popular because of this trend (Li et al., 2026). The plants *Azadirachta indica* (neem) *Allium sativum* (garlic) *Syzygium aromaticum* (clove) *Thymus vulgaris* (thyme) *Cymbopogon citratus* (lemongrass) and *Eucalyptus globulus* have demonstrated effective pest and disease control against multiple mushroom related threats (Latif et al., 2025). The shelf life, stability and field efficacy of botanical products have been further enhanced through recent advancements in green chemistry and formulation science which include nanoemulsions, microencapsulation, controlled release systems and the synergistic combinations with microbial biocontrol agents (Manta et al., 2025). Mushroom farmers encounter challenges with standardization and dose optimization together with phytotoxicity and residue profiling and registration processes and economical commercialization (Sharma et al., 2024; Kumar et al., 2024). This review presents recent technological advancements and evaluates the sustainability potential of plant u based bioactive products while conducting a comprehensive assessment of existing pest and disease threats to cultivated mushrooms and determining research needs to incorporate botanical elements into present day mushroom production methods.

## 2 Global Status and Economic Importance of Cultivated Mushrooms

Mushroom cultivation has developed from a minor specialized industry into a worldwide agrifood business which creates sustainable waste recycling solutions for nutraceutical markets and financial growth in rural areas and food security (Pérez-Morenoet al. 2021). The worldwide production of mushrooms and truffles has experienced rapid growth because consumers now prefer plant-based protein, healthy foods and pharmaceutical products (FAOSTAT 2025). Asia continues to be the world's leading production hub with China producing the majority of the world's output, followed by nations like India, Japan, South Korea, Indonesia and Thailand (Itubochiet al.,2025). The commercial sectors in North America and Europe maintain strong operations which focus on selling high value fresh and processed mushrooms (Carvalhoet al. 2024). The mushroom industry operates through a wide range of products which include fresh fruit, dried mushrooms, canned goods, powder, dietary supplements, mycelium-based compounds and pharmaceutical extracts (Atri et al., 2024). White button mushrooms *(Agaricus bisporus)* maintain their position as the main mushroom species in global trade because consumers prefer them and they have a long shelf life and their supply networks function effectively (Patil al., 2026). The low-cost cultivation technology of oyster mushrooms (*Pleurotus spp.*) together with their ability to grow on agricultural waste and their capacity to survive in diverse environmental conditions has made these mushrooms extremely popular in developing countries (Saifullah al., 2026). The medicinal and nutraceutical properties of reishi *(Ganoderma lucidum)* and shiitake *(Lentinula edodes)* enable these mushrooms to enter premium market segments (Ferraro et al., 2022).

Mushrooms generate superior economic returns through their production which requires minimal land resources and their ability to grow in vertical space according to (Thakur et al. 2025). Women led businesses and urban growers and small-scale farmers benefit from mushrooms because these fungi need minimal land for their short production cycles and fast cash generation (Cetin et al., 2025). Periurban and rural communities in multiple tropical and subtropical countries have adopted mushroom farming as an effective way to diversify their income sources (Anand et al., 2025). Mushroom production enables the conversion of low value lignocellulosic waste materials into high value edible products. Agricultural byproducts such as wheat straw rice straw maize stalks cotton waste sawdust banana leaves and sugarcane bagasse serve as substrates for producing nutrient rich biomass while reducing environmental waste burdens (Patil et al., 2026). Spent mushroom substrate functions as a circular economy resource which provides organic fertilizer animal feed vermicompost material and bioenergy production feedstock. The mushroom business faces major economic threats from six different factors which include pest outbreaks and disease epidemics and postharvest spoiling and rising input costs and labor shortages and climate related production instability. The extremely perishable nature of mushrooms together with their sensitivity to quality makes even minor fly and mite and fungal disease infestations result in production and quality losses which lead to major financial damage. The increasing demand for sustainably grown mushrooms which contain no residue has created pressure on growers to reduce their use of synthetic pesticides while maintaining profitable operations. The mushroom industry needs to implement safe sustainable methods which use advanced technology for protecting crops because these methods will serve as important assets for its future business operations, which require higher production volumes. The present development of the mushroom industry depends on the use of plant based bioactive substances, precision agriculture methods, better sanitary protocols and combined pest control methods according to studies by (Chaudhary et al., 2026). Mushroom cultivation functions as an essential component of circular bioeconomy systems because it transforms agricultural waste materials into valuable food products while producing different types of marketable products (Figure 1).

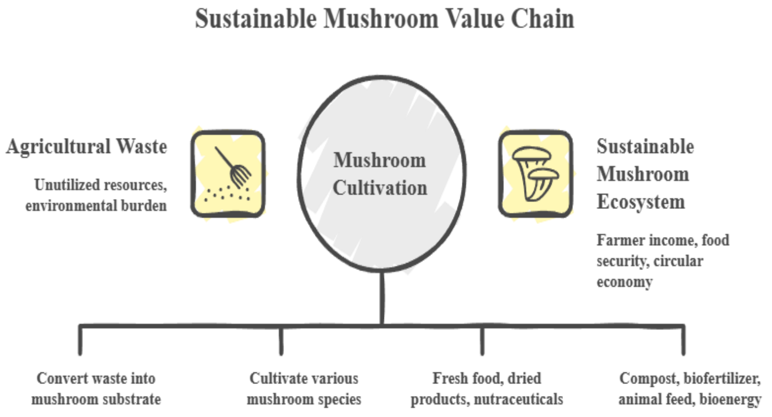


**Figure 1.** Global mushroom production value chain highlighting waste-to-food conversion, diversified market products and circular bioeconomy benefits

## 3 Major Pests of Cultivated Mushrooms

The regulated environmental conditions which include high humidity and moderate temperature together with an abundance of organic matter and minimal sunlight create optimal conditions for many arthropod and nematode pests which develop their populations in mushroom cultivation environments (Abdelkhalek et al., 2025). The controlled production environments of mushroom facilities enable quick pest development through hidden transmission routes that operate via personnel movement and irrigation system use and compost and casing material and tools and infected spawn or substrate movement (Gea et al., 2021). The extreme fragility of mushrooms as products means that even minor visual defects cause market value loss and shelf-life reduction which occurs when pests reach their lowest population level (Navarro et al., 2021). Via the direct intake of mycelium, primordia, stalks, caps and fruiting bodies together with the fungal spores and bacteria and mites and nematodes which spread through indirect pathways pests damage the cultivated mushrooms (Manta et al., 2025). The repeated infestations lead to a decrease of mycelial vigor and a delay of cropping cycles and a reduction of flush numbers and an increase of contamination pressure throughout production sites (Sharma et al., 2025). The main pest groups which affect mushroom farms include beetles, flies, springtails, mites and nematodes while the severity of these pests depends on mushroom type and hygienic standards and substrate management and climate conditions (Dou et al., 2025).

### 3.1 Fly Pests

Flies serve as the main destructive force which impacts mushroom cultivation as the most important pest in this agricultural practice. The production systems of button and oyster mushrooms face their main challenges from sciarid flies and phorid flies (Rijal et al., 2021). The adult flies get attracted to the wet growing spaces and compost odors which they use to lay their eggs on the substrate and casing materials (Sattar et al., 2021). The active feeding of larvae on mushroom mycelium leads to patchy development problems which result in deformed mushrooms and decreased yields (Marčić et al., 2025). Secondary fungal infections together with bacterial soft rot infection will enter through larval tunneling which leads to stalk and cap access points (Sharma et al., 2025). The presence of adult flies causes higher disease rates in growth rooms because they transmit Pseudomonas, Cladobotryum and Trichoderma spores through their roles as mechanical carriers (Thirumeni et al., 2024). The market rejection of fresh mushrooms occurs because heavy insect infestations cause mushrooms to lose their original appearance and firmness (Manawasinghe et al., 2025).

### 3.2 Beetles and Springtails

Various beetle species establish their presence in mushroom houses because of inadequate sanitation combined with the existence of organic waste materials. The larvae and adult beetles consume mycelium and compost to produce holes and scars on surfaces which they subsequently contaminate (Rijal et al., 2021). Beetles spread diseases because they travel between contaminated areas and clean environments (Devi et al., 2024). Small springtails can become serious agricultural threats because they thrive in environments with constant moisture. The organisms decrease pinhead formation and impede spawning activities through their feeding on fungal hyphal networks and developing biological material (Kumar et al., 2024). The presence of these organisms in growing rooms indicates that the space contains either high moisture levels or poor drainage systems or decaying organic material (Hajam et al., 2024).

### 3.3 Mite Infestations

Mushroom farms have hidden pests which include mites that become visible only when their population reaches significant levels. Numerous species cause pitting, browning, cavities and rough cap surfaces by directly consuming mycelium, spores and fruiting bodies (Gea et al., 2021). Certain mites serve as primary sources of infestation because they invade compost, straw , and stored substrates before crop establishment (Li et al., 2024). Mites spread contamination by carrying bacterial cells and fungal spores on their bodies (Carrasco et al., 2021). The presence of mushroom infestations destroys the visual appeal of mushrooms and shortens their shelf life, resulting in reduced market value. The combination of insufficient hygiene practices and contaminated casing soil and defective substrate pasteurization methods leads to recurring mite infestations (Navarro et al., 2021).

### 3.4 Nematodes

Nematodes create a serious challenge for mushroom cultivation because their presence is often not detected. The feeding behavior of mycophagous nematodes leads to two negative effects because they consume fungal hyphae which results in mycelial growth suppression and reduced substrate colonization capacity (Sharma et al., 2024). The extreme conditions cause beds to become uneven which results in water-soaked areas that produce unpleasant odors and prevent the growth of typical fruiting bodies (Kumar et al., 2024). Certain nematodes infiltrate growing mushrooms, which leads to softness and discolouration and deformed tissues and decreased shelf life (Li et al., 2024). The major sources of infestation originate from untreated water and infected compost ingredients and improperly sterilized equipment and previously infested growth structures

(Carrasco et al., 2021). Nematodes spread rapidly through wet organic materials because prevention and sanitation methods provide better results than advanced treatment options.

### 3.5 Economic Impact of Pest Infestations

The mushroom industry experiences pest damage which leads to production losses that exceed the direct impact on their output. The visual quality of products declines which results in higher contamination risks and shorter shelf life and increased labor expenses and postponed harvest times and ongoing cleaning costs (Manawasinghe et al., 2025). Export markets will refuse consignments that contain any trace of insects or evidence of feeding damage (Wang et al., 2024). The successful operation of profitable mushroom enterprises depends on their ability to implement early detection methods together with sustainable prevention strategies.

### 3.6 Need for Sustainable Pest Management

Chemical insecticides and fumigants served as the main methods for controlling mushroom pests until regulations began to restrict chemical residues and worker safety and environmental protection (Sharma et al., 2026). Plant-based bioactive materials and sticky traps and exclusion methods and sanitation programs and biological control agents currently serve as sustainable alternatives for plant protection (Habib et al., 2026). Major pest groups in cultivated mushroom production cause serious economic losses through feeding injury to mycelium and fruiting bodies, contamination spread, quality deterioration, and overall yield reduction (**Figure 2)**.

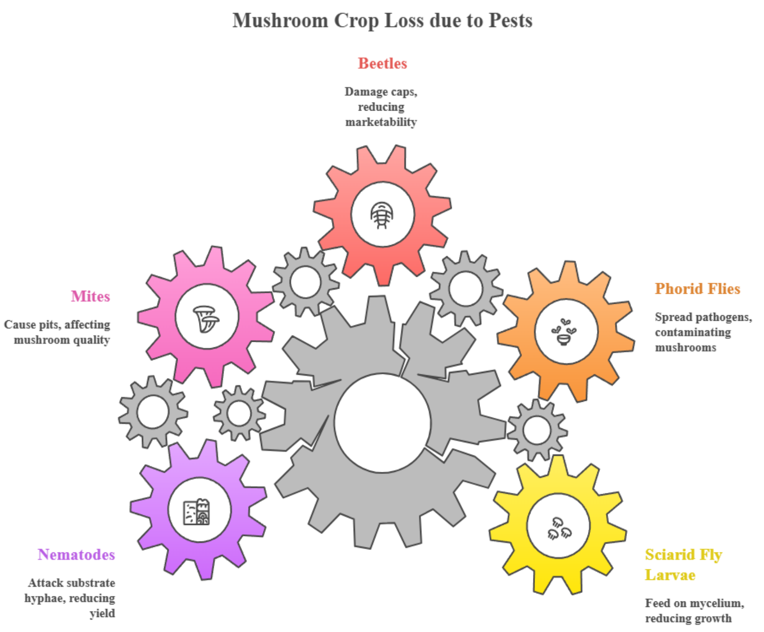


**Figure 2.** Major pests associated with cultivated mushroom production systems and their principal modes of damage, including feeding injury to mycelium and fruiting bodies, contamination spread, quality deterioration and yield reduction.

## 4 Major Diseases of Cultivated Mushrooms

The high disease risk in commercial mushroom cultivation results from the extreme susceptibility of cultivated mushrooms to both microbial competition and pathogen attacks in their warm and humid and enclosed growing conditions (Potočnik et al., 2024). Production rooms designed for optimal mycelial growth face dangerous pathogen outbreaks because they lack proper hygiene control (Gea et al., 2021). The introduction of pathogens results in production losses because they spread rapidly through air currents and irrigation splash and tools and workers and insects and casing materials and contaminated compost and infected spawn (Carrasco et al., 2021). Mushroom farms experience disease outbreaks which spread rapidly throughout their entire growing season whereas field crops develop their diseases over extended time periods (Gajanayake et al., 2025). The complete shutdown of a room together with its subsequent cleaning process becomes essential when a situation reaches its peak, resulting in substantial economic losses (Dou et al., 2025). The three main types of infections that affect cultivated mushrooms are often classified as bacterial, viral and fungal.

### 4.1 Fungal Diseases

#### *4.1.1 Green Mold Disease*

The Trichoderma species which cause green mold disease represents one of the most destructive pathogens that attacks cultivated mushrooms. The pathogen competes with mushroom mycelium for resources and space as it rapidly colonizes compost and casing layers (Hidalgo-Sanz et al., 2024). White cottony growth appears as the first symptom which develops into green growth after intense sporulation begins. The disease advancement leads to mushroom mycelium developing thin spotty areas which results in poor pinning and a significant decrease in yield (Abdelkhalek et al., 2025). Green mold outbreaks occur when there is contaminated substrate and inadequate pasteurization and the environment has poor cleanliness standards and excessive moisture content and temperature fluctuations (Sattar et al., 2021). The quick response to sanitation processes becomes essential because Trichoderma spores spread rapidly through the air and between people.

#### *4.1.2 Dry Bubble Disease*

The most prevalent disease that affects button mushrooms throughout the world occurs as dry bubble disease which results from the fungus Lecanicillium fungicola that scientists used to call Verticillium fungicola (Gea et al., 2021). The symptoms of the condition include brown lesions and enlarged stems and fractured caps and deformed fruiting bodies that resemble air pockets and malformed mushrooms. The infected mushrooms experience marketability loss even though their total yield remains intact.

The disease spreads through spores which are transmitted by air and insects and water splash and handling activities (Sharma et al., 2024). The presence of contaminated mushrooms which remain uncollected for an extended period of time creates dangerous sanitary conditions that lead to an increase in disease transmission.

#### *4.1.3 Cobweb Disease*

Cobweb disease, commonly associated with *Cladobotryum* species, appears as fast-growing white fluffy mycelium over casing soil and mushroom surfaces (Gea et al., 2021). Under humid conditions, the pathogen spreads rapidly like a web across beds and fruiting bodies. Infected mushrooms discolor, soften, collapse, and rot quickly (Sharma et al., 2024). Air movement and harvesting operations can accelerate disease spread.

### 4.2 Bacterial Diseases

#### 4.2.1 Bacterial Blotch

Another extremely damaging fungal disease in mushroom farms is wet bubble disease which is brought on by Mycogone perniciosa (Abdelkhalek et al., 2025). The fungus produces abnormal fleshy growths which do not resemble typical mushrooms. Infected tissues may exhibit amber or brown exudates along with an unpleasant odor in later stages (Potočnik et al., 2024). The entire growing room will become contaminated during severe outbreaks which will lead to the loss of all productive flushes. Bacterial blotch disease which affects mushrooms remains one of the most widespread bacterial diseases in mushrooms. *Pseudomonas tolaasii* serves as the primary cause of this disease (Marčić et al., 2025). The symptoms include diminished visual attractiveness, damage to surfaces, and development of yellow to brown greasy patches on caps which result in reduced product longevity (Sattar et al., 2021). The disease depends on three essential factors high humidity conditions, poor airflow and moisture accumulation on mushroom surfaces. Bacterial blotch disease damages fresh market value because it reduces the visual appeal of mushrooms which actually preserves most of the harvest (Bello et al., 2025).

#### *4.2.2 Soft Rots and Secondary Bacterial Infections*

Soft rot results from slime development and an unpleasant odor and rapid postharvest deterioration that occur when multiple types of opportunistic bacteria infect mushrooms which sustain mechanical damage or insect damage. The pathogens become most harmful to people during instances of cold-chain failure and packing and harvesting activities (Liu et al., 2024).

### 4.3 Viral Diseases

Mushroom viral infections create invisible economic impacts because they reduce production and uniformity whereas visible lesions exist in their infected state (Peña et al., 2023). The infected harvests show symptoms through pinning delays, reduced mushroom size, abnormal fruiting body development, premature opening, color irregularities and uncharacteristic flushing patterns (Sattar et al., 2021). The viral complexes become difficult to control because they establish permanent presence in contaminated facilities and infected cultures and spawn lines.

### 4.4 Economic Impact of Diseases

Mushroom disease outbreaks cause both direct and indirect damages which include reduced crop production and spoiled agricultural produce and increased expenses for cleaning and calculated costs to stop farming and decreased trust from customers (Itubochi et al., 2025). The fresh marketability of mushrooms suffers when even small disease symptoms appear because mushrooms need to be harvested and sold alive (Wu et al., 2025).

### 4.5 Need for Eco-Friendly Disease Management

The cultivation of mushrooms has traditionally employed conventional fungicides and disinfectants but present-day farmers need to use safe alternative methods because they face two main challenges chemical resistance development, chemical residue hazards and worker safety hazards and potential crop vulnerability hazards (Tyagi et al., 2025). Modern mushroom farms now use plant extracts and essential oils and biological antagonists and integrated hygiene-based disease management methods as their effective control methods (Manawasinghe et al., 2025). Major fungal, bacterial, and viral diseases, which show specific symptoms, cause quality problems and major yield reductions in cultivated mushrooms according to the evidence (Figure 3).

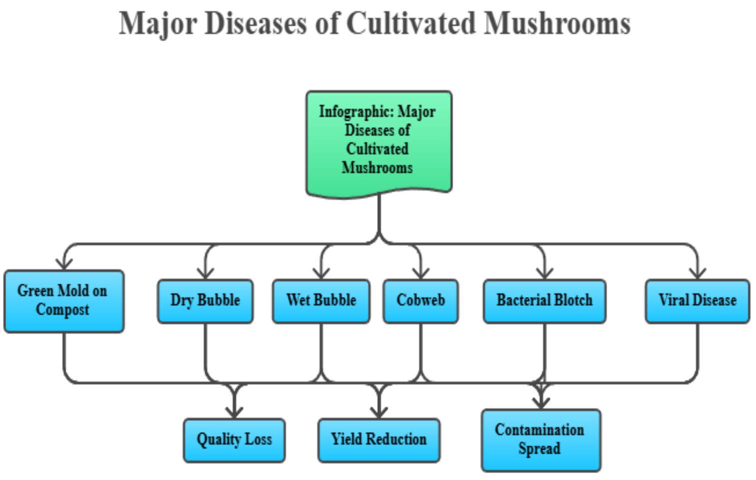


**Figure 3.** Major fungal, bacterial, and viral diseases affecting cultivated mushrooms and their characteristic symptoms associated with quality deterioration and yield loss.

## 5 Limitations of Synthetic Chemicals in Mushroom Production

The use of synthetics fungicides, insecticides, disinfectants and fumigants has been important in mushroom crop protection against pests and diseases especially in intensive commercial systems (Peña et al., 2023). Related products may exhibit quick knockdown of pests and temporary control of harmful organisms and thus are used by growers that experience an immediate outbreak (Navarro et al., 2026). Nonetheless the complex and inherent effects of the long-term reliance on chemical regulation have developed severe technical, environmental, economic and communal health-related challenges that question the sustainability of contemporary mushrooms production (Malakar et al., 2025). Mushrooms are picked very often and cooked in situ with minimum processing compared to field crops which makes these products sensitive to issues with pesticide residue (Itubochi et al., 2025). The mushroom fruiting bodies are soft tissues and contain high moisture levels so improper use of pesticides near the harvest period can increase the risk of residues and violate the food safety standards demanded by the domestic and export markets (Zou et al., 2024). Growers are under further pressure to cut on synthetic chemical additions as consumers are increasingly demanding food without residues and organically produced foods (Abdelkhalek et al., 2025).

### 5.1 Development of Resistance

Using two or more active ingredients/ chemicals with similar mode of action repeatedly can result in the development of resistance to fungal pathogens, insect pests and other mites (Gea et al., 2021). The treatment is resistant to successfully treating a population and it consequently increases with time leading to the gradual ineffectiveness of previously dependable products (Hidalgo-Sanz et al., 2024). Mushroom systems are particularly difficult to manage resistance since closed spaces can expose pests and pathogens to numerous applications of various crop cycles (Silva et al., 2024). A number of mushroom pathogens have been demonstrated to exhibit decreased susceptibility to widely used fungicides in commercial systems necessitating the need to employ rotational control and chemical-free options (Sharma et al., 2025). Even after resistance occurs, growers tend to react by adding frequency or switching to more costly chemicals further escalating production expenses.

### 5.2 Residue and Food Safety Concerns

Mushrooms are being sold as luxury health products with high nutrient and bioactive content so chemical residues are in direct contradiction to consumer perceptions of safe and healthy foods (Samarasiri et al., 2026). Consignments that contain residues exceeding the accepted levels can lead to sales rejection, trade restrictions, loss of brand reputation and penalties by authorities (Yang et al., 2024). Due to the repeated nature of mushrooms harvesting with very short cycles pesticides need to be applied in the right time. Improper use or non-compliance with pre-harvest intervals may greatly heighten the risk of contamination (Li et al., 2022). Small-scale growers with minimal technical advice are of particular concern with this problem.

### 5.3 Adverse Effects on Mushroom Crop Itself

Growing mushrooms are fungi i.e. the fungicides designed to inhibit pathogens could have the negative effect on the crop mycelium as well as spawn run, pinna or fruiting when used or utilized inadvertently (Ghimire et al., 2021). Most of the time chemical stress decreases biological performance, slows the growth of crops or decreases the quality of mushrooms with no detectable visual phytotoxicity (dela Cruz et al., 2025). Like, detergent disinfectants or fumigants applied in growing rooms can also affect useful microbial equilibrium in compost or casing substances which indirectly affects crop growth (Hait et al., 2025).

### 5.4 Worker and Environmental Health Risks

Mushroom farms can be confined areas in which frequent spraying, fogging or the use of disinfectants may expose workers to chemical vapors and aerosols as well as residual (Gómez-Jiménez et al., 2025). Occupational health issues can arise due to chronic exposure absent of the use of proper protective equipment (Boonyingsathit et al., 2025). Poor disposal of chemical containers, used wash water, and used substrate can also cause environmental pollution of soil and water systems (Shao et al., 2024). Despite the fact that mushroom farms occupy smaller land plots compared to field crops when such concentrated facilities are utilized actively with intensive use of chemicals there is still a risk of local ecological hazards.

### 5.5 Regulatory Restrictions and Market Pressure

The toxicological and environmental risks of many older pesticide molecules are leading to their restriction/removal in many countries (Su et al., 2025). The pesticides registered on mushrooms are usually not numerous due to the fact that mushrooms are a speciality crop with less market compared to cereals or fruits (Mohanta et al., 2025). Consequently, growers can have limited legal alternatives in managing their pests. Meanwhile the need to adopt sustainability certifications, traceability mechanisms, and low-residue production standards which is increasingly demanded by the supermarkets and importing companies drives the industry towards less harmful solutions (Masbernat et al., 2025).

### 5.6 Economic Limitations

Chemical dependency may bring the costs of production up because of many reprints, changes in the product due to resistance, the necessity to use protective equipment, tests of residues and crop loss due to unsuccessful control measures (Thakur et al., 2025). Smallholders are particularly prone to this since expensive pesticides might fail to deliver any certain yield in cases of poor sanitation or reinfestation (Anand et al., 2025).

### 5.7 Need for Alternative Strategies

Such restrictions have not only increased interest in the world on integrated pest management methods, fusing sanitation, surveillance, biological control and plant-based products (Ahmed et al., 2025). The botanical extracts and essential oils have the most potential since most of them have multi-target mechanisms of action, low persistence and compatibility with sustainable mushroom production systems (Abbas et al., 2026). The use of synthetic chemicals for mushroom production leads to various significant problems which scientists have identified through their research (Figure 4).

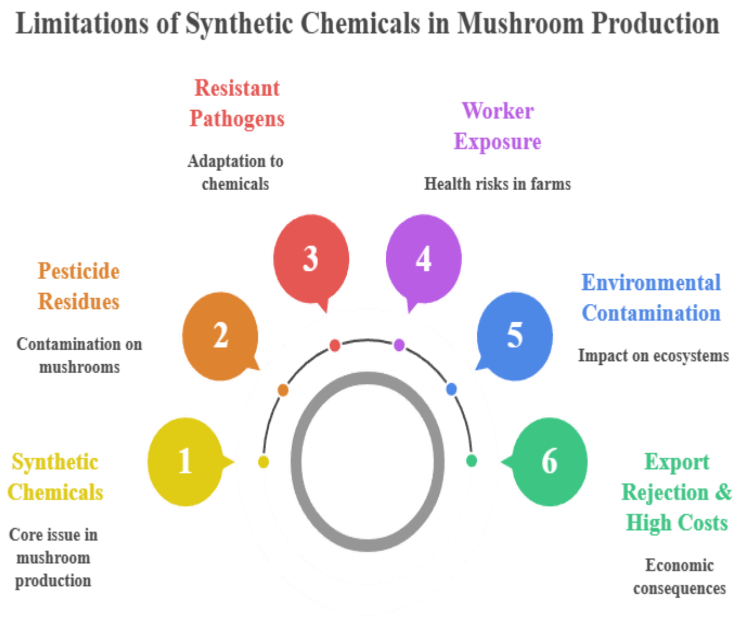


**Figure 4.** Key limitations of synthetic chemical dependence in mushroom production, including residue risks, resistance development, worker exposure, environmental concerns and reduced market acceptance.

## 6 Plant-Derived Products for Mushroom Pest and Disease Management

Increasing fears about the impact of pesticides as residues, heightened resistance situations and environmental pollution and consumer desire to have foods without residues have prompted renewed attention toward plant-based products as safer options to protect mushroom crops (Geng et al., 2024). Whole plants, seeds and leaves, roots, bark, flowers or extracted bioactive compounds are also used as botanical pesticides all of which have insecticidal, repellent, fungicidal, bactericidal, acaricidal and nematicidal effects (JAMS et al., 2023). Plant-based products are particularly appealing in mushroom farming due to their tendency to degrade more quickly than traditional pesticides more often multiple-effect action and with the ability to be combined with sanitation programs, biological control and organic farming (Manta et al., 2025). Furthermore, botanicals can be generated locally using existing plentiful plant materials providing affordable chances to the small and middle growers in tropical and subtropical areas (Wadhwa et al., 2024).

### 6.1 Neem-Based Products

Neem is one of the most popular botanical sources of pest control across the world. It has biologically active limonoids in its seeds, leaves, oil and cake with azadirachtin being one of them and salannin, nimbin and other similar substances (Kumari et al., 2025). These components serve as antifeedants, growth regulators, oviposition deterrents, repellents or contact toxicants against most pests of insects (Jamir et al., 2025). Neem-based formulations have demonstrated potential in mushroom production systems to combat sciarid flies, phorid flies, mites and nematodes and amendments based on neem cake could enhance the hygiene of substrates and overcome contamination by soil-borne contaminants (Najafzadeh-Nansa et al., 2026). Neem extracts also have medium antifungal and antibacterial properties and can be used as the part of the integrated management programs (Najafzadeh-Nansa et al., 2026).

### 6.2 Essential Oils

Aromatic plants are used to extract oils that have high levels of volatile terpenes, phenolics, aldehydes and alcohols that have strong antimicrobial and insecticidal properties (Zhang et al., 2024). Clove, thyme, oregano, lemongrass, eucalyptus, peppermint and cinnamon oils have been found to have promise as agents to mitigate fungal pathogens, bacterial contamination, mites and flying insects (Grzyb et al., 2025). Their vapor activity is especially applicable in walled mushroom houses where flying pests, spores and so on are prevalent. Essential oils can prevent the spore germination, damage bacterial membrane, disrupt breathing and repel insects as adults (Abdullah et al., 2025). Nevertheless the concentration should be optimized as the use of large doses can influence mushroom mycelium or cause the change in odor properties.

### 6.3 Garlic and Sulfur-Containing Botanicals

Garlic (*Allium sativum*) is reported to have the general-use antimicrobial effects since sulfuric compounds including allicin, diallyl sulfides and ajoene (Singha et al., 2025). Extraction of Garlic has been shown to inhibit bacterial and various fungal pathogens that infect mushrooms production (Ali et al., 2025). Due to this natural volatility and high bioactivity, the potential of garlic can be investigated as a room disinfection support botanical that is sanitation-friendly and as a disease suppressant or in combination with other plant extracts (Liu et al., 2024).

### 6.4 Eucalyptus, Citrus and Other Tree-Based Extracts

Extracts and oils from eucalyptus and citrus species contain cineole, limonene, citronellal and related compounds known for antimicrobial and insect-repellent effects (Siam et al., 2025). These materials have shown potential against storage molds, bacterial blotch organisms and flying insect pests in controlled environments (Adetuyi et al., 2024). Due to their pleasant aroma and volatility, they may be suitable for low-residue integrated programs where repeated harsh chemical applications are undesirable.

### 6.5 Moringa, Artemisia, Tagetes and Multipurpose Plants

Cineole, limonene, citronellal and other compounds extracts and oils of the eucalyptus and citrus species have antimicrobial and insect-repelling properties (Sun et al., 2023). These materials have exhibited resistance to storage molds bacterial blotch organisms and flying insect pests in a controlled setting (Rai et al., 2022). Their genial aroma and volatile nature might make them appropriate in low-residue integrated programs which do not require a repeated chemical harsh treatment.

### 6.6 Current Limitations

Although having great potential other limitations to the use of botanicals include variation in concentration of active ingredient, lower shelf life, lack of formulation stability, toxicity at high dosage and inconsistency in the field performance when used in commercial setup (Sud et al., 2024). Advanced formulations and standardization are hence necessary to massive adoption.

### 6.7 Strategic Importance for Mushroom Industry

Shifting the paradigm towards sustainable mushroom growing implies the substitution of individual dependence on the chemical properties with the use of diverse management instruments. One of the most viable and market-corresponding alternatives is represented by plant-derived products since it will help address the need to reduce residues, ensure environmental stewardship and make consumers trust crops protection (Roy et al., 2024). The various plant-derived products in cultivated mushroom systems function as multiple solutions to combat insect pests and mites and nematodes and microbial diseases (Figure 5).

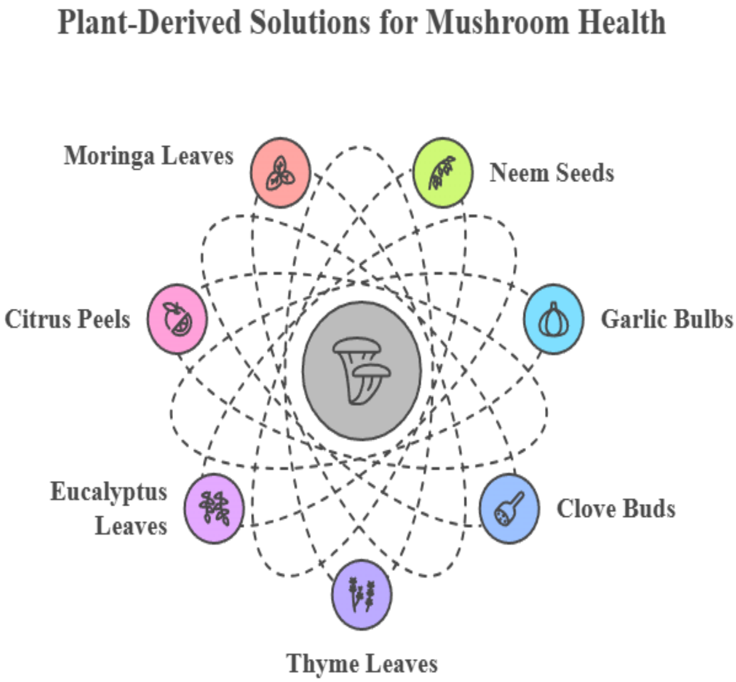


**Figure 5.** Major plant-derived products and their multifunctional roles in managing insect pests, mites, nematodes and microbial diseases in cultivated mushroom systems.

## 7 Challenges and Limitations of Plant-Derived Products in Mushroom Production

Although these products made of plants have significant potential as ecological alternatives to synthetic pesticides there are a number of scientific, technical and commercial drawbacks to their wide use in mushroom production facilities (Wadhwa et al., 2024). The chemical composition of plant extracts and essential oils can vary by the genotype of the plant its geographical origin and the effects of climatic factors, stages of harvest and method of extraction which is one of the most important limitations (Tian et al., 2025). Consequently, the efficacy of the products might vary in different locations and production inquiry. The relatively short residual activity and relative low environmental stability of most botanical compounds is another significant challenge. Integrity of active constituents can be affected by heat, light, oxygen and humidity resulting in a shorter shelf life and field persistence in comparison to traditional synthetic pesticides (Aguiar et al., 2026). This is especially topical in mushroom-producing countries of the tropics where temperatures and moisture are likely to be too hot to allow the products to perform as required. Standardization of doses is also an important attribute since the low dosages can result in insufficient pest suppression whereas the high dosage can suppress mushroom mycelial development, decelerate pinning, influence the quality of fruit bodies or modify aroma properties (Manta et al., 2025). Growing mushrooms are extremely sensitive biological system hence appropriate optimization of time of application, formulation and concentration are necessary before commercial utilization. The obstacles to commercialization make further adoption of botanical products slow. Several plant extracts are only at laboratory or pilot level and few products have been through a complete toxicological assessment, residue profiling and approval of registration and market development with regard to specific products with mushrooms (Karunarathna et al., 2026). Besides that the extraction technologies, the costs of the formulation, packing and control over the quality can raise the production costs particularly in the small businesses. The gap of knowledge among growers is also not small. The farmers might not be trained on how to prepare them, how they can be used together with the other farm practices, how safely they can be applied and how they can be used in conjunction with sanitation or biological control programs (Molitorisová et al., 2025). Lack of proper technical direction will cause poor outcomes and lack of confidence in botanical solutions when used without proper technical direction. This means that despite the promise of significant potential of plant-derived products in the creation of mushrooms that are sustainable through the protection of the product and its properties the future of the development of the formulation will be based on the standardization of active components, optimized formulations, validation of the field under commercial conditions, support of the regulatory environment and proper training of farmers (Ojha et al., 2025).

## 8 Future Perspectives

It is assumed that the key to a sustainable mushroom protection will merely lie in the successful fusing of plant-based products with the current cultivating systems, bio control solutions and agro-management instruments. The production of botanical products will become more commercially relevant both at the domestic and export level as there is a consistent growth in consumer demand of mushrooms free of residues as well as organically certified mushrooms. Among the best research directions is the formulation of superior formula that includes nano, microencapsulation and controlled-delivery systems. These technologies have the capability of enhancing the stability, shelf-life, solubility and bioefficacy of volatile or rapid degradable plant compounds under commercial growing conditions. Improved formulations can also minimize the applications frequency and enhance between them and mushroom crops. The other significant opportunity is to integrate microbial biocontrol agents like antagonistic bacteria, advantageous fungi, predatory mites and entomopathogenic organisms with plant-derived products. These combined measures can possibly offer more comprehensive security and alleviate the pressure of resistance that can arise when controlled measures are applied exclusively through a certain approach. Management of mushroom disease is also likely to be changed with the use of digital tools in agriculture. An automated system of environmental monitoring, sensors, artificial intelligence and image-based diagnostics will be capable of detecting the outbreak of pests early and improving the botanical application timeline. Accurate targeting would enhance effectiveness without wasting products and low production costs. The future studies should also aim to screen unexploited native plants with the purpose of identifying new bioactive compounds particularly in tropical and subtropical areas under biodiversity-rich regions. The scientific study of many local species has not been carried out although they might also hold pesticidal/antimicrobial promise (Islam et al., 2025). Their validation has the potential to create region-specific and low-cost techniques to smallholder mushroom growers. Policies that support simplify the registration process, volumes of private-public partnerships and grower training models will be the key to commercialization and acceptance of botanical products in the mushroom business (Jacob et al., 2025). In general the use of plant-based products will become important elements of integrated pest management systems of the next generations to achieve sustainable and resilient mushrooms collections.

## 9 Conclusion

Mushroom cultivation is a fast growing and economic sector with inherent economic contribution to food security, rural livelihoods, waste recycling and a booming functional foods market. Yet the productivity and profitability of mushroom farming is in serious danger due to a multiplicity of insect pests, mites, nematodes, bacterial pathogens, fungal infections and viral diseases that may lead to recognizable yield and quality losses. Traditional reliance on artificial pesticides has offered temporary containment yet there have been growing concerns on the pesticide leftovers, resistance, environmental pollution, government limitations and the demand among consumers on healthier foods have raised the need to look into sustainable options. Examples of plant-derived products which have a great potential in the application as mushroom pest and disease management tools include neem extracts, essential oils, garlic compounds, eucalyptus oils and other botanicals which are environmentally-friendly. Their multifunctional use i.e. insecticidal, repellent, antifungal, antibacterial and nematocidal attributes make them useful additions in the integrated crop protection strategies. Moreover, their suitability with organic agriculture and organic markets without residue also underline their commercial importance. In spite of this potential, further adoption continues to be limited by challenges with variability in active compounds, instability of formulations, inadequate field validation, regulatory challenges and a lack of awareness among growers. This will mean that the progress in the future will rely on scientific standardization, improved delivery technology, commercial level efficacy testing and good support of the producers in terms of extension. In general, all products of plant origin are not only alternatives to synthetic chemicals but a tactical instrument to create resilient, sustainable and market-oriented mushroom production. With their combination with sanitation, natural guidelines of biological control and specific cultivation techniques the level of chemical addiction can be willingly lowered, preserving the level of crop success, food safety and environmental responsibility.

**Author Contributions**

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**Conflict of Interest**

The authors declare that they have no financial, professional, commercial, institutional, or personal conflicts of interest that could have influenced the content, interpretation, or conclusions of this article.

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**Data Availability**

No new experimental, laboratory, or field dataset was generated or analysed for this study. All evidence discussed in the review was obtained from published scientific literature and publicly available sources cited in the manuscript.

**Informed Consent**

Not applicable. No human participants were recruited and no primary personal data were collected.

**Use of Generative AI**

The authors declare that no generative artificial intelligence tools were used to conduct the literature analysis, generate the scientific content, interpret the evidence, or formulate the conclusions presented in this article.

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