Mushroom diseases: Impact and management strategies

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Mushroom diseases:
Impact and management strategies

- Mushrooms; affected adversely by a large number of **biotic and abiotic agents/ factors**.
- Among the biotic agents, **fungi, bacteria, viruses, insects** and **mites** cause damage to **mushrooms directly or indirectly.**
- A number of **harmful fungi** are encountered in **compost** and **casing soil** during the **cultivation of mushrooms**.
- Many of these act as **competitor moulds** thereby adversely **affecting spawn run** whereas others attack the **fruit bodies at various stages** of crop growth producing **distinct disease symptoms**.
- Resulting in **complete crop failure depending upon the stage of infection, quality of compost and environmental conditions**.

Mushroom diseases:
Impact and management strategies

Mushroom diseases/Mycoparasites

BIOTIC (Infectious)

Gea *et al.*, 2021

Fungal; *Trichoderma* spp. (green mould), *Lecanicillium fungicola* (dry bubble), *Mycogone perniciosa* (wet bubble), and *Cladobotryum dendroides* (cobweb) etc

Bacterial; *Pseudomonas tolaasii* (Brown/ bacterial blotch) & *Bacillus* Spp. (Wet spot/Sour rot)

Virus; La France disease and Mushroom Virus X (MVX)

ABIOTIC (Non infectious)

Abiotic disorders;
Stroma, Cracked mushrooms, Rose comb, Weepers/Leakers, Hard caps/hard gill, hollow core, or scaly caps etc

Mushroom diseases:
Impact and management strategies

Mycoparasites/Diseases at different stages of cultivation

- General distribution of various competitor moulds and pathogenic fungi is as follows:

I. Those occurring mainly in compost/substrate include:

i. Olive green mould (*Chaetomium olivaceum* and other spp.),

ii. Ink caps (*Coprinus* spp.)

iii. Green moulds (*Aspergillus* spp. *Penicillium* spp. and *Trichoderma* spp.),

iv. Black moulds (*Mucor* spp., *Rhizopus* spp.) and

v. other (*Myriococcum praecox*, *Sporotrichum* sp., *Sepedonium* sp., *Fusarium* spp., *Cephalosporium* spp., *Gliocaldium* spp., and *Papulospora* spp.).

Mushroom diseases:
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Mycoparasites/Diseases at different stages of cultivation (Contd.)

II. Fungi occurring in compost and in casing soil:

i. White plaster mould (*Scopulariopsis fimicola*)
ii. Brown plaster mould (*Papulospora byssina*),
iii. Lipstick mould (*Sporendonema purpurescens*),
iv. False truffle (*Diehliomyces microsporus*) and
v. Green moulds (*Aspergillus* spp. *Penicillium* spp. and *Trichoderma* spp.)

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Mycoparasites/Diseases at different stages of cultivation (Contd.)

III. **Fungi occurring on and in casing soil and/or on the growing mushrooms:**

i. Cinnamon mould (*Peziza ostracoderma*),

ii. Wet bubble (*Mycogone perniciosa*),

iii. Dry bubble (*Verticillium fungicola*),

iv. Cobweb (*Cladobotryum dendroides*),

v. Pink mould (*Trichothecium roseum*) and

vi. Green moulds (*Aspergillus* spp. *Penicillium* spp. and *Trichoderma* spp.)

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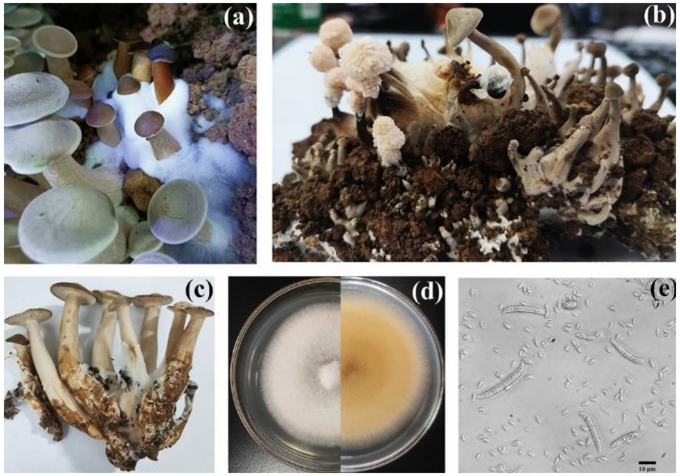
Mycoparasites/Diseases at different stages of cultivation (Contd.)

IV. Fungi attacking the fruit bodies only:

- ✓ Fusarial rot (*Fusarium* spp.).
- ✓ At any phase of growth an undesirable growth or development of certain moulds can occur and can adversely affect the final mushroom yield.



Mushroom diseases: Impact and management strategies

Mycoparasites/Diseases of cultivated mushrooms

S.No	Disease	Pathogen
A) Fungal diseases		
1	**Dry Bubble**	***Lecanicillium fungicola***
2	**Wet Bubble**	***Mycogone perniciosa***
3	**False Truffle**	***Diehliomyces microsporus***
4	**Green Mold**	***Aspergillus* spp. *Penicillium* spp. and *Trichoderma* spp**
5	Olive green mould	*Chaetomium olivaceum* and other spp.
6	Ink caps	*Coprinus* spp
7	Black moulds	*Mucor* spp., *Rhizopus* spp.
8	Pink mould	*Cephalothecum roseum*
9	Sepedonium yellow mould	*Sepedonium* and *Chrysoporium*
10	White plaster mould	*Scopulariopsis fimicola*
11	Brown plaster mould	*Papulospora byssina,*
12	Lipstick mould	*Sporendonema purpurescens*
13	Cinnamon mould	*Peziza ostracoderma*
14	Other moulds & mycoparasites	*Myriococcum praecox*, *Sporotrichum* sp., *Sepedonium* sp., *Fusarium* spp., *Gliocaldium* spp., and *Papulospora* spp.

Mushroom diseases: Impact and management strategies

Mycoparasites/Diseases of cultivated mushrooms

S.No	Disease	Pathogen
B) Bacterial diseases		
1	Bacterial Blotch	*Pseudomonas tolaasii*
2	Wet Spot/Sour rot	*Bacillus* spp
3	Mummy	*Pseudomonas* spp
C) Viral diseases		
1	La France,	Unassigned ds-RNA/ MBV- Mushroom Bacilli form virus
2	X diseases	MVX- Mushroom virus X

Mushroom diseases:
Impact and management strategies

Important Mycoparasites/Diseases of cultivated mushrooms

Dry bubble disease (*Lecanicillium fungicola)*

Symptoms:

- ✓ **Whitish mycelial** growth initially appears on the casing surface which has the tendency to **turn grayish yellow with age.**
- ✓ **If the pinhead infected** at early stage, **typical onion shaped mushrooms** are produced and a small **pimples** are developed on their cap.
- ✓When mushrooms are **affected at later stage, the deformed mushrooms** can be seen because of restricted growth of infected tissue on one side and normal growth on the other side of stipe.
- ✓The strips of surface tissue of **stipe may also peels away from the curved side.**

Mushroom diseases:
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Dry bubble disease (*Lecanicillium fungicola*)

PSI; Casing soil harbors the primary inoculum of the fungus.

SSI; Secondary spread of the pathogen within the crop and in other crop rooms takes place **by spores (conidia) through air, flies, water splashes and pickers** etc.

Favourable Conditions: High humidity, poor aeration, delayed picking of diseased mushroom and temperature above 18^{0} C favours diseases development and spread

Management:

a) Adopt **strict hygienic measures** at the farm

(b.) and spent compost should be properly disposed off to avoid primary infection. **Use only sterilized casing soil**

(c.) After spawning, spray dichlorovos @ 30 ml/100 lit. water /100m3 area to check the flies

(d.)Remove all affected mushroom before picking and watering and take them away in plastic bags, **Spray the affected patch with 2% formalin**

(e) Spraying with dithane Z-78 (0.15%) at weekly interval or one spraying of sporgon (0.15%) 7-9 days after casing.

(f.) Cook out at the end of cropping

Mushroom diseases:
Impact and management strategies

Wet bubble disease (*Mycogone perniciosa*)

Symptoms

✓When young pin heads are infected, they develop into distorted masses of mushroom tissues, which look like a "**cauliflower**".

✓Small **amber to dark brown drop of liquid develops** on the surface of the undifferentiated tissue in very high humid conditions.

✓ At this stage an unpleasant odour comes out from the infected beds.

Symptoms of wet bubble disease

Mushroom diseases:
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Wet bubble disease (*Mycogone perniciosa*)

PSI; Casing soil, air and spent compost. Pathogens survive for long time in casing soil and spent compost.

SSI; In the crop room, secondary spread of the pathogen is by air, water splashes, flies and pickers.

Favourable Conditions: High humidity, warm temperatures (22–25°C), and poor hygiene favor disease development

Management

a, Strict hygienic conditions should be maintained.

b. Use only sterilized casing soil.

c. One spraying with dithane Z-78 (0.15%) at weekly interval.

d. Cook out (70^0 C for 12 hrs.) the crop room at the end of cropping

Mushroom diseases:
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Cobweb disease (*Cladobotryum dendroides*)

Symptoms:

- ✓ The disease is first appearing as small circular patches of grayish white mycelium on the casing surface.
- ✓ As the disease progress, a fluffy white mycelium grows over the mushrooms which **look like a cotton balls**.
- ✓ Eventually they turn brown, begin to rot and die-off.

PSI-It normally introduced into the crop room by **contaminated casing soil or spores through air.**

SSI- Secondary spread is **by air movement, pickers, water splashes** etc.

Favourable Conditions: High relative humidity and temperature favours the disease.

Symptoms of cobweb

Mushroom diseases:
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Cobweb disease (*Cladobotryum dendroides*)

Management:

a. Use sterilized casing soil only

b. Temperature and R.H. should not go beyond 18^0 C and 85 %, respectively

c. Use spore filters at the ventilations.

d. Spraying with sporgon (0.3%), dithane - 78, Benlate or Bavastin (0.2%) between the flushes.

e. Cook out at the end of cropping

Mushroom diseases: Impact and management strategies

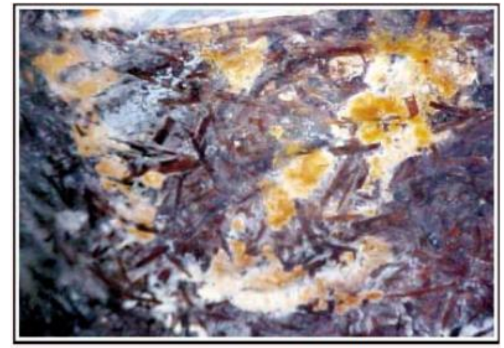
Common Moulds

Name of Mould	Causal Organism	Symptoms / Effects	Favourable Conditions
Green mould	*Trichoderma* spp.	White mycelium turns green, inhibits pin formation, reduces yield.	High humidity, poor composting.
Yellow mould	*Sepedonium chrysosporium*	White to yellow growth on compost with metallic odour; 5–20% yield loss.	19–20°C, high moisture.
Pink mould	*Cephalothecum roseum*	White growth turns pink on casing; may cause total crop failure.	25°C, pH 6.0.
Ink caps	*Coprinus* spp.	Thin mushrooms liquefy into black ink; indicates ammonia presence.	High ammonia in compost.
Olive green mould	*Chaetomium olivaceum*	White growth turns olive green; weak spawn run.	Improper pasteurization, poor ventilation.
White plaster mould	*Scopulariopsis fimicola*	White patches on compost; poor spawn growth.	High pH (>8.0), excess moisture.
Brown plaster mould	*Papulospora byssina*	Whitish growth turns brown; sandy feel on rubbing.	Wet compost, poor straw, high temp.
False truffle	*Diehliomyces microsporus*	Reddish-brown fruiting bodies in compost; severe yield loss (up to 75%).	Contaminated soil, high humidity.
Cinnamon mould	*Chromelosporium fulva*	White to golden brown patches; cup-like fruit bodies.	Over-pasteurization, wet compost.

Major Diseases of Mushroom and their Management

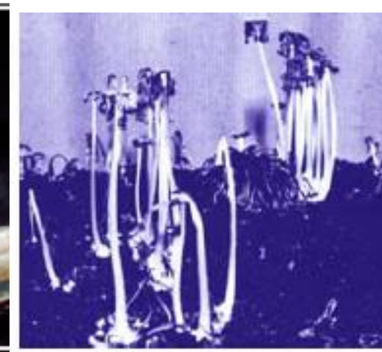
Green mould Symptoms

Green mould (*Trichoderma* spp.)

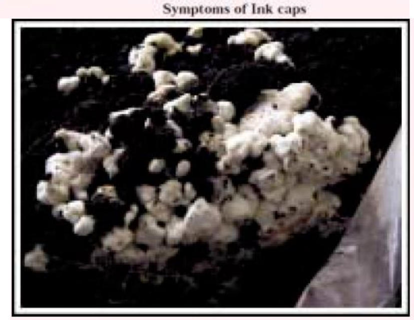


Symptoms of brown plaster mould

Symptoms of yellow mould



Symptoms of Ink caps



Symptoms of false truffle

Mushroom diseases:
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Management of moulds

i. Proper hygienic conditions should be observed.

ii. Compost and casing soil must be pasteurized/ sterilized.

iii. Compost should be ammonia (NH_3) free (not more than 8-10 ppm) and pH should be in between 7.2-7.5 at spawning.

iv. Use spore filters to prevent the entry of spores of these moulds.

v. During spawn run the beds are covered with papers, should be moistened twice a week with 0.5% formalin.

vi. Temperature and relative humidity in the crop room should be maintained as per requirement of the crop.

vii. Stumps and dead mushrooms must be removed regularly from the beds.

viii. Spray with Dithane M-45 (0.15%), bavastin (0.05%) at 8-10 days intervals

ix. Cook-out at the end of crop.

Mushroom diseases:
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Bacterial Blotch (*Pseudomonas tolaasii*)

This is the most serious bacterial disease in cultivated mushrooms.

Symptoms:

- It **causes brown, sunken lesions on caps and stalks, leading to a sticky surface and reduced market value.**
- Small yellow to brown spots that enlarge and coalesce; affected mushrooms become sticky and discolored.

Mode of spread: The bacterium thrives on wet mushroom surfaces and spreads through contaminated water, tools, or insects.

Favorable conditions: They generally develop under high humidity, poor ventilation, and prolonged surface wetness.

Management:

- **Maintain relative humidity around 80–85%.**
- **Avoid water condensation on caps; dry surfaces after watering.**
- **Ensure proper ventilation and temperature control.**
- **Use chlorinated or disinfected water (100 ppm chlorine).**

Mushroom diseases:
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La France Disease (Die-back or Watery Stripe); MBV- Mushroom Bacilli form virus

- Several viruses infect mushrooms, collectively known as ***mycoviruses***. They interfere with normal growth and **cause deformities, yield loss, and premature aging**.
- Its one of the most common viral disease

Symptoms:

- This virus affects *Agaricus bisporus*, **causing elongated stalks with small, deformed caps (drumstick appearance).**
- Affected mycelium becomes weak, and the fruiting is delayed or completely stops.
- Thin, elongated stipes, premature cap opening, water-soaked tissues, and uneven fruiting.

Drumstick symptom of mushroom infected by La France Disease

Mushroom diseases:
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La France Disease (Die-back or Watery Stripe)

Transmission: Through spores, mycelial fragments, or contaminated tools.

Management:

- Adopt strict sanitation and disinfection protocols.
- Steam sterilize rooms and tools after every crop.
- Remove and destroy infected mushrooms before spore release.
- Use virus-free spawn and resistant cultivars.

Mushroom diseases:

Impact and management strategies

Commonly used fungicides in mushroom cultivation

Fungicide (Active Ingredient)	Type / Mode of Action	Target Disease	Mushroom Crop	Country / Region of Use	Notes / Restrictions
Thiabendazole (TBZ)	Benzimidazole; systemic; inhibits β-tubulin → blocks mitosis	Green mold (Trichoderma spp.), post-harvest decay	Button mushroom (Agaricus bisporus)	US (registered), China (used), India (off-label / experimental)	Indoor use; limited to spawning stage in US; risk of resistance with repeated use
Chlorothalonil	Contact, multi-site inhibitor; prevents spore germination	Green mold (Trichoderma spp.)	Button mushroom	US (registered)	Often used in rotation with TBZ; contact fungicide only
Prochloraz	Imidazole systemic; DMI, inhibits ergosterol synthesis	Cobweb disease (Cladobotryum spp.), green mold	Button mushroom, Shiitake (Lentinula edodes)	China (used), India (experimental/off-label)	Used in mushroom houses; low residue; indoor application recommended
Carbendazim / Benomyl	Benzimidazole; systemic; inhibits β-tubulin	Green mold, cobweb disease	Button mushroom	India (off-label), China (sometimes), limited US use	Risk of resistance; often replaced by TBZ or Prochloraz
Sodium Dichloroisocyanurate (NaDCC)	Chlorine-based sanitizer; substrate sterilization	Substrate contamination, surface molds	Button mushroom, Oyster mushroom	China (used), global (sanitizer)	Not a conventional fungicide; used mainly for hygiene
Seboctylamine Acetate	Organic fungicide	Cobweb disease (Cladobotryum spp.)	Button mushroom	China (research / trials)	Mostly experimental; limited commercial use
Trichoderma-based biocontrols	Biological fungicide; competitive colonization	Green mold (Trichoderma spp.)	Button mushroom, Oyster mushroom	US, India, Europe	Used as sustainable alternative; growing adoption in integrated management
Azoxystrobin	QoI systemic; inhibits mitochondrial respiration	Green mold	Oyster mushroom	China (reported use)	Experimental; applied in substrate or growing house
Prophylactic sanitizers (e.g., Hypochlorite)	Disinfectant / surface sterilant	General contamination control	All cultivated mushrooms	Worldwide	Not a fungicide per se; part of hygiene management

Mushroom diseases: Impact and management strategies

Alternative bio-based formulations for eco-friendly management of mycoparasites of cultivated mushrooms

- BCAs/biopesticides
- Essential oils from botanicals
- Plant extracts and
- and compost teas

Mushroom diseases:
Impact and management strategies

Commercial bio-protection agents for mushroom disease management.

Bioprotection Agents	Description	Examples of Products	Targets
Bacillus velezensis QST 713	Bacterium	Serenade Max (Bayer CropScience)	*T. harzianum*
Bacillus amyloliquefaciens	Bacterium	Amylo-X (Certis)	*T. aggresivum* *T. aggresivum*
subsp. *plantarum* D747 *Bacillus amyloliquefaciens* MBI 600	Bacterium	Serifel (BASF)	*T. harzianum*
Streptomyces griseoviridis K61	Bacterium	Mycostop (Danstar Lallemand)	*T. aggresivum* *L. fungicola*
Streptomyces lydicus WYEC 108	Bacterium	Actinovate (Novozymes)	*T. aggressivum* *L. fungicola*
Clonostachys rosea J1446	Fungus	Prestop (Danstar Lallemand)	*T. aggressivum* *L. fungicola*

(Dejan *et al.,* 2025)

Mushroom diseases:
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Efficacy of commercial *B. velezensis* QST 713 based bioprotection agents against mushroom diseases evaluated under mushroom growing conditions.

Application Time	Concentration/Rate	Target	Efficacy (%)	References
4 d after the casing time	8×10^9 CFU g^{-1} in 1 L H_2O m^{-2}	*T. aggressivum*	48	[4]
2 d after the casing time			52–57	[110]
Spawn grain treatment			50	[112]
4 d after casing time		*T. harzianum*	56	[4]
At the casing time			44	[32]
2 d after the casing time		*L. fungicola*	42–62	[110]

(Dejan *et al.*, 2025)

Mushroom diseases: Impact and management strategies

Alternative bio-based formulations employed to fight mycoparasites of cultivated mushrooms: EOs from botanicals, plant extracts, and compost teas

Table 1. Alternative bio-based formulations employed to fight mycoparasites of cultivated mushrooms: EOs from botanicals, plant extracts, and compost teas (last 15 years).

Target Mycoparasite/Disease	Bio-Based Formulation	Biocontrol Activity	Proposed Mechanism	Reference
Lecanicillium fungicola/Dry Bubble Disease (DBD)	Three concentrations (5%, 10%, and 15%) filtered, microfiltered, and sterilized aerated compost teas (ACT) from grape marc compost.	Filtered and microfiltered ACT exhibited 100% inhibition of mycelium growth in vitro.	Compost excreted siderophores (due to the microorganisms present in grape marc compost) which were responsible for inhibiting the mycelium growth.	Dianez et al. [49]
	Essential oils (EOs) of *Matricaria chamommilla*, *Mentha piperita*, *M. spicata*, *Lavandula angustifolia*, *Ocimum basilicum*, *Thymus vulgaris*, *Origanum vulgare*, *Salvia officinalis*, *Citrus limon* and *C. aurantium*.	Oils from oregano and thymus species, containing phenolic compounds (carvacrol and thymol) showed the best inhibitory activity against the *L. fungicola* in vitro.	Components of EOs are responsible for the inhibitory effect (linalyl acetate, linalool, limonene, α-pinene, β-pinene, 1,8-cineole, camphor, carvacrol, thymol, and menthol).	Soković and van Griensven [50]
	EOs from lavender, anise, chamomile, fennel, geranium, oregano, parsley, and sage.	Oregano and geranium oils showed the most toxic effect against the *L. fungicola* var. *fungicola* when exposed to the volatile phase.	Components of EOs are related to their toxicity, oregano oil had a high content of carvacrol and thymol, geranium oil main components were citranelol and geraniol.	Tanović et al. [51]
	Untreated, autoclaved, or microfiltered non-aerated compost teas (NCT) from different sources (spent mushroom substrate, olive oil husk + cotton gin trash composted and mixed with rice husk, grape marc compost, and cork compost) were assayed against three *L. fungicola* isolates. Compost:water ratios of 1:4 and1:8 (w/v) were used and extraction periods of 1, 7, and 14 days.	Untreated NCT obtained the same % of mycelium inhibition as prochloraz-Mn. Autoclaving or microfiltration lost the activity. A period of 1–7 days and 1:4 dilution is recommended.	Antifungal activity due to the action of the active microbiota in the CT.	Gea et al. [52]
	ACT and NCT were obtained from four different composts: spent mushroom substrate compost, grape marc compost, greenhouse horticultural crop residues compost, and vermicompost.	ACT and NCT filtrates suppressed the mycelial growth of the mycopathogen in vitro. Sterilization by autoclaving or microfiltration removed partially or totally the inhibitory effect.	The efficacy of ACT and NCT depends on the microbiota present in them.	Marin et al. [53]

Mushroom diseases:
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Alternative bio-based formulations employed to fight mycoparasites of cultivated mushrooms: EOs from botanicals, plant extracts, and compost teas

Table 1. *Cont.*

Target Mycoparasite/Disease	Bio-Based Formulation	Biocontrol Activity	Proposed Mechanism	Reference
Cladobotryum spp./ Cobweb disease	EOs from lavender, anise, chamomile, fennel, geranium, oregano, parsley, and sage.	Oregano and geranium oils showed the most toxic effect against the *Cladobotryum* sp. when exposed to the volatile phase.	Components of EOs are related to their toxicity, oregano oil had high content of carvacrol and thymol, geranium oil main components were citranelol and geraniol.	Tanović et al. [51]
	Biofungicide: tea tree oil (Timorex 66 EC), based on the EO of *Melaleuca alternifolia.*	Tea tree oil was less toxic than prochloraz–manganese in vitro against *C. dendroides* isolates. Tea tree oil (drench application at 1%) applied in infected trials caused a significant reduction in cobweb disease and was not toxic against the crop (*A. bisporus*).	Most components of tea tree oil (highest antifungal activity due to the components: terpinen-4-ol, α-terpineol, linalool, α-pinene, and β-pinene) have activity against a range of fungi.	Potočnik et al. [58]
	Inhibitory and fungicidal activity of two EOs, cinnamon (*Cinnamomum verum*) and clove (*Syzygium aromaticum*) tested by microdilution, macrodilution fumigant, and macrodilution contact method.	Clove oil showed the strongest activity than cinnamon, showing the lowest minimum inhibitory concentration (MIC) in vitro against *C. dendroides.* Macrodilution fumigant method showed a stronger antifungal effect than the contact method.	Antifungal activity could be related to the presence of phenolic compounds within the EOs tested, such as eugenol, dominant phenolic compound in clove oil with proved strong antimicrobial activity.	Luković et al. [57]
	EOs extracted from 12 botanicals: *Syzygium aromaticum, Pelargonium graveolens, L. angustifolia, Cupresus sempervirens, M. piperita, Santolina chamaecyparissus, Citrus sinensis, Pogostemon patchouli, Thymus mastichina, Thymus vulgaris, Eucalyptus globulus,* and *R. officinalis.*	EOs obtained from clove, peppermint, patchouli, and rose geranium showed high antifungal activity in vitro against *C. mycophilum* with very low ED_{50} levels of 1.6, 7.4, 0.6, and 0.3%, respectively.	GC-MS showed eugenol in clove (86.38%), L-Menthol (41.97%) in peppermint, patchouli alcohol (33.40%) in patchouli, and citronellol (31.51%) in rose geranium as main components of these fungitoxic EOs.	Dianez et al. [59]
	Aqueous extracts from seven dried botanicals: mint leaves and stem (*Mentha longifolia*), garlic bulb (*Allium sativum*), turmeric rhizome (*Curcuma longa*), ginger rhizome (*Zingiber officinale*), clove seeds/buds (*Syzygium aromaticum*), cinnamon seeds (*Cinnamomum zeylanicum*), and neem leaves (*Azadirachta indica*).	*Syzygium aromaticum*, exhibited the maximum inhibition (99.48%) in vitro against *C. mycophilum* in amended PDA.	The spectra corresponding to the bioactive chemical constituents in *S. aromaticum* using Fourier transform infrared (FTIR) spectroscopy showed maximum intensive peak at 3375 cm–1 that represents the OH groups, this peak could correspond to antifungal phenolic compounds.	Idrees et al. [60]

Mushroom diseases:
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Alternative bio-based formulations employed to fight mycoparasites of cultivated mushrooms: EOs from botanicals, plant extracts, and compost teas

Table 1. *Cont.*

Target Mycoparasite/Disease	Bio-Based Formulation	Biocontrol Activity	Proposed Mechanism	Reference
	EOs obtained by hydrodistillation from five aromatic plants (*Lavandula × intermedia*, *Salvia lavandulifolia*, *Satureja montana*, *Thymus mastichina*, and *Thymus vulgaris*).	*T. vulgaris* and *S. montana* (ED_{50} = 35.5 and 42.8 mg L^{-1}, respectively) showed the highest toxicity in vitro for inhibiting the mycelial growth of *C. mycophilum*, and the best selectivity between the pathogen and *A. bisporus*. EO from *T. vulgaris* showed some efficacy at controlling cobweb disease when used at the 1% rate in artificially infected crop trials.	The antimicrobial compounds carvacrol (17.22%) for *S. montana* and thymol (25.78%) for *T. vulgaris* were the most abundant phenolic compounds of these EOs, that also content contained a significant proportion of the biological precursors of the phenolic components p-cymene.	Gea et al. [61]
Mycogone perniciosa/Wet Bubble Disease (WBD)	EOs isolated from savory (*Satureja thymbra*) and sage (*Salvia pomifera* ssp. *calycina*).	*S. thymbra* EO showed better antifungal activity against *M. perniciosa* than *S. pomifera* oil in vitro by the microatmosphere method, minimal inhibitory quantity (MIQ), of 0.05 µL mL^{-1} and minimal fungicidal quantity (MFQ), of 0.25 µL mL^{-1}.	The antifungal activity is related to the composition of the EOs as assessed by GC-MS: in *S. thymbra*, oils were γ-terpinene (23.2%) and carvacrol (48.5%), while in *S. pomifera* oil were α-thujone (20.4%) and β-thujone (36.1%).	Glamočlija et al. [62]
	EO from *Critmum maritimum* extracted from fresh plant material.	The essential oil of *C. maritimum* possessed antifungal activity in *vitro*, with MIQ = 1 µL disc-1 and MFQ = 20 µL $disc^{-1}$ against *M. perniciosa*.	The chemical composition of *C. maritimum* EOs related to antifungal activity. With the two most abundant components, α-pinene (26.29%) and limonene (31.74%) showing strong antifungal activity.	Glamočlija et al. [63]
	EOs from lavender, anise, chamomile, fennel, geranium, oregano, parsley, and sage.	Oregano and geranium oils showed the most toxic effect against the *M. perniciosa* when exposed to the volatile phase.	Components of EOs are related to their toxicity, oregano oil had a high content of carvacrol and thymol, geranium oil's main components were citranelol and geraniol.	Tanović et al. [51]
	EOs from seven botanicals.	*Thymus vulgaris* oil possessed the highest antifungal activity in vitro against *M. perniciosa* by microatmosphere method, with MIQ and MFQ of 0.02 µL mL^{-1} of air. *Pistacia terebinthus* showed the lowest antifungal effect, MIQ and MFQ of 0.16 and 0.65 µL mL^{-1} of air.	Oils from thymus species contain phenolic compounds (carvacrol and thymol) showing proved antimicrobial activity.	Potočnik et al. [64]

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Alternative bio-based formulations employed to fight mycoparasites of cultivated mushrooms: EOs from botanicals, plant extracts, and compost teas

Table 1. *Cont.*

Target Mycoparasite/Disease	Bio-Based Formulation	Biocontrol Activity	Proposed Mechanism	Reference
	Forty EOs, seven pure terpenoids, and one phenylpropanoid.	Lemon verbena (*Lippia citriodora*), lemongrass (*Cymbopogon citratus*) and thyme (*Thymus vulgaris*) oils substantially inhibited the growth of *M. perniciosa* in vitro, with the best selectivity between pathogen and host. Lemon verbena or thyme oils was able to control the development of WBD in casing-infected trial with innocuous effect to the host.	The main components of these oils, nerol and thymol, determined by GC–FID and GC–MS, showed antifungal activity, selective to the pathogen *M. perniciosa*.	Regnier and Combrinck [65]
	EOs from clove, castor, eucalyptus, olive, citrullina, and cinnamic aldehyde	Cinnamon oil in the form of cinnamic aldehyde (2.5 and 5 $\mu L\ L^{-1}$) and eucalyptus oil (2.5 and 7.5 $\mu L\ L^{-1}$) were the most effective to inhibit *M. perniciosa* in vitro with non-detrimental effect to the host strain at these doses.	Antifungal activity probably related to the chemical composition of the EOs and extracts (mainly due to the presence of phenolic compounds).	Sabharwal and Kapoor [66]
	Organic extracts of seeds of *Moringa peregrina*.	Moringa seed extracts inhibited the growth of both *M. perniciosa* in lower concentration than *A. bisporus*, through in vitro tests.	Candidates for the antifungal components in the seeds can be fatty acids like oleic acid and palmitic acid. Secondary metabolites such as sothiocyanates (99.9% of the volatile components of Iranian Moringa seeds) are also candidates for antifungal activity.	Shokouhi and Seifi [67]
Trichoderma spp./ Green mold	Essential oils (EOs) of *Matricaria chamommilla, Mentha piperita, M. spicata, Lavandula angusti folia, Ocimum basilicum, Thymus vulgaris, Origanum vulgare, Salvia officinalis, Citrus limon* and *C. aurantium*.	Oils from oregano and thymus species, containing phenolic compounds (carvacrol and thymol) showed the best inhibitory activity against the *T. harzianum* in vitro.	Components of EOs are responsible for the inhibitory effect (linalyl acetate, linalool, limonene, α-pinene, β-pinene, 1,8-cineole, camphor, carvacrol, thymol, and menthol).	Soković and van Griensven [50]
	EO was *extracted from* Lippia alba by Clevenger hydrodistillation.	*L. alba* EO presented antifungal activity, with MIC of 0.6 mg mL-1 and MFC of 1.250 mg mL-1, against *Trichoderma viride*.	Geranial identified by GC-MS and NMR was described to be the main fungicidal component of this EO (50.9% of the chemical composition of *L. alba* EO)	Glamočlija et al. [68]

Mushroom diseases:
Impact and management strategies

Alternative bio-based formulations employed to fight mycoparasites of cultivated mushrooms: EOs from botanicals, plant extracts, and compost teas

Table 1. *Cont.*

Target Mycoparasite/Disease	Bio-Based Formulation	Biocontrol Activity	Proposed Mechanism	Reference
	Biofungicide: Timorex Gold (BM 608) EC (Stockton-Agrimor, Petach Tikva, Israel) based on tea tree oil (tea tree oil 23.8%; solvent 65.4%; ethanol 4.0%; NaOH 2.3%, and surfactant 4.5%), based on the EO of *Melaleuca alternifolia*.	Tea tree oil did not exhibit significant antifungal activity in vitro (ED_{50} = 11.9–370.8 mg L^{-1}) against *T. atroviride*, *T. koningii*, *T. virens*, *T. aggressivum f. europaeum*, *and T. harzianum*. The biofungicide based on *B. subtilis* demonstrated greater effectiveness in preventing disease symptoms than tea tree oil. However, when combined with prochloraz-Mn, tea tree oil showed higher antagonism.	Most components of tea tree oil (highest antifungal activity due to the components: terpinen-4-ol, α-terpineol, linalool, α-pinene, and β-pinene) have activity against a range of fungi.	Kosanović et al. [69]
	EOs extracted from 12 botanicals: *Syzygium aromaticum*, *Pelargonium graveolens*, *L. angustifolia*, *Cupresus sempervirens*, *M. piperita*, *Santolina chamaecyparissus*, *Citrus sinensis*, *Pogostemon patchouli*, *Thymus mastichina*, *Thymus vulgaris*, *Eucalyptus globulus and R. officinalis*.	*Trichoderma aggressivum* f.sp. *europaeum* was less sensitive than *C. mycophilum* to the same EOs tested in vitro. It was most inhibited by peppermint, patchouli, and rosemary EOs with ED_{50} levels of 12.7%, 11.7%, and 3.4% in the growth medium, respectively.	GC-MS showed L-Menthol (41.97%) in peppermint, patchouli alcohol (33.40%) in patchouli, and citronellol (31.51%) in rose geranium as main components of these fungitoxic EOs.	Dianez et al. [59]
	An active film prepared by corn starch, polyvinyl alcohol, and carvacrol nanoemulsions (CNE).	More than 10% CNE applied into the film formulation showed inhibition against *Trichoderma* sp. Films with 25% CNE exhibited excellent antifungal activity with an inhibitory zone of 47 mm.	Efficient antifungal phenolic compound carvacrol.	Kong et al. [70]
	Plants essential oils and plant extracts of six medicinal plants (*Lippia* citriodora, *Ferula gummosa*, *Bunium persicum*, *Mentha piperita*, *Plantago* major, *and Salvadora* persica). In addition to a chimera peptide of camel lactoferrin (antimicrobial component of camel milk).	*L. citriodora*, *B. persicum*, and *M. piperita* treatments could completely prevent the growth of *T. harzianum* under in vitro conditions through disc diffusion method.	Antifungal activity probably related to the chemical composition of the EOs and extracts (mainly due to the presence of phenolic compounds).	Tanhaeian et al. [71]

Abiotic (Non-Infectious) Diseases of Mushrooms

Abiotic or non-infectious diseases of mushrooms

Major Causes: Abiotic disorders arise mainly due to

- **Temperature extremes** – high or low temperatures affect compost and fruiting.
- **Improper humidity or ventilation** – leads to abnormal growth and discoloration.
- **High CO_2 concentration** – causes elongated stems and poor cap development.
- **Water quality and pressure** – excess chlorine or hard water damages mushroom tissues.
- **Toxic chemicals** – fumes from oils, paints, or formalin can deform mushrooms.
- **Poor compost or casing preparation** – unbalanced pH and moisture encourage stress conditions.

➢ **These factors directly influence the mycelial growth, fruiting, yield, and quality of mushrooms.**

➢ **Understanding these disorders and maintaining optimal conditions are essential for successful cultivation.**

Abiotic (Non-Infectious) Diseases of Mushrooms

Common Disorders:

- **Stroma:** Dense white mycelial growth on compost or casing due to high CO_2 and moisture.
- **Weepers/Leakers:** Water exudation from caps or stems caused by moisture imbalance.
- **Hard Cap/Open Veil:** Premature cap opening due to stress or chemical fumes.
- **Hollow Core/Brown Pith:** Hollow stems and brown discoloration from water stress.
- **Purple Stem:** Stems turn purple after harvest due to enzyme activity.
- **Rose Comb:** Deformed caps caused by oil or chemical vapours.
- **Scales (Crocodile Skin):** Cracked cap surface due to dry air or formalin vapours.
- **Long-Stemmed Mushrooms:** Caused by high CO_2 and poor aeration.
- **Brown Discolouration:** Due to high temperature, chlorine, or water pressure.

Abiotic (Non-Infectious) Diseases of Mushrooms

Common Disorders:

Cracked mushroom

Rose comb in mushroom

Hollow core and brown pith in mushroom

Abiotic (Non-Infectious) Diseases of Mushrooms

Management Practices

•Maintain **optimum temperature (22–25°C)** and **relative humidity (80–90%)** in cropping rooms.
•Ensure **proper air circulation** and maintain CO_2 below harmful levels.
•Use **fresh, healthy spawn** and **well-pasteurized compost** and casing materials.
•Avoid exposure to **toxic fumes**, oils, or chemical disinfectants inside farms.
•Apply water gently and check bed moisture before irrigation.
•Keep growing rooms **clean and hygienic**; disinfect regularly with approved solutions.
•Remove and destroy **abnormal or damaged mushrooms** to avoid contamination.
•Maintain proper sanitation from **spawn preparation to harvest**.

- **Abiotic or non-infectious diseases are a major challenge in mushroom cultivation, often resulting in reduced yield and poor quality.**

- **These disorders can be minimized by Scientific management of temperature, humidity, and ventilation, along with good hygiene and use of quality inputs, ensures healthy and high-yielding mushroom crops**

Mushroom diseases:
Impact and management strategies

Impact of mushroom diseases

- Worldwide, mushroom diseases cause **significant yield losses**, which vary depending on the specific pathogen, the crop management, and the environmental conditions
- Some of the most economically damaging diseases can cause losses **from 5% to over 90% in severely affected crops**.

General Factors Influencing Yield Loss

Factor	Impact on Yield
Time of Infection	Early infections lead to maximum yield loss.
Inoculum Level	Higher pathogen concentration → greater yield reduction.
Environmental Conditions	Warm, humid environments favor disease spread.
Pathogen Strain	Aggressive strains cause more severe outbreaks.
Farm Hygiene	Poor sanitation increases pathogen buildup and spread.

Mushroom diseases: Impact and management strategies

Impact of mushroom diseases

Disease Name	Causal Organism	Main Host (Example)	Geographical Impact / Regions	Reported Yield Reduction (%)	Key Notes / Remarks
Dry Bubble	*Lecanicillium fungicola*	*Agaricus bisporus* (Button mushroom)	Europe, Worldwide	**Commonly 1–5%; can reach 20%+** under poor control	Estimated €300 million annual losses in Europe; aggressive isolates may increase mushroom count but reduce healthy yield.
Wet Bubble	*Mycogone perniciosa*	*Agaricus bisporus*	China, India (Kashmir)	Average **15–30%;** up to **65%** in severe cases	Yield loss severity linked to pathogen inoculum rate; highly destructive under humid conditions.
Green Mold	*Trichoderma aggressivum*	*Agaricus bisporus*	UK, Ireland, Worldwide	**29–56%** (low inoculum, 10^{-4}); **68–100%** (high inoculum, 10^{-3}); epidemics caused up to 40% loss	One of the most aggressive competitors; major epidemics in 1990s caused crop collapse.
Bacterial Blotch	*Pseudomonas* spp.	*Agaricus bisporus* and others	UK, Worldwide	**Typically 5–10% loss; up to 30%+** in serious cases	Additional 10% downgrade in market value; annual losses up to $2 million per farm.
False Truffle	*Diehliomyces microsporus*	*Agaricus bisporus*	Worldwide	**Up to 75%** when infection occurs early	Affects compost, inhibits mycelial growth; difficult to eradicate once established.

Mushroom diseases: Impact and management strategies

Basic principles for diseases management

- Exclusion– prevent entry and establishment
- Elimination– removal or reduction of pathogen
- Avoidance– strict sanitation, environmental control, and use of good quality mushroom seed
- Protection– timely treatment to prevent infection & spread
- Therapy– curative measures to limit pathogen

- To prevent a build-up of pathogen propagules; strong hygiene standards:
- Disinfection,
- Cook-out,
- Foot-dips,
- Door-seals, filters, flies-control will be necessary through out the cropping period and every crop.

Mushroom diseases: Impact and management strategies

The compost is living ecosystem; suitable for mushroom growth and development. However, its not a selective medium. Use of pesticides is limited; management relies on cultural and hygienic practices. Only a few fungicides are actually used or approved mostly for contamination control (e.g., green mold)

Therefore the main issues that need to be addressed in future research

- **Manipulating growing environments to favor mushrooms**
- **Need to focus on plant based fungicides**
- **Search for promising BCAs & Evaluation of already identified Bio agents, and**
- **Determining ecological interactions and compatibility between various bio-protection agents in mushroom**
- **Further need to focus on generation of genomic resources of mycoparasites through WGS to understand the mechanisms involved in host parasite interactions, and to design programs for breeding resistant varieties of economically important mushrooms**

Mushroom diseases:
Impact and management strategies

Thank You