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A REVIEW

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Diseases, moulds, insect-pests and mites of mushroom

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ABSTRACT

Mushroom is defined as macro-fungus with distinctive edible fruiting body which can be either epigeous or hypogeous. Cultivation of edible mushrooms carries great relevance in todays' world in the context of a burgeoning population growth and extreme pressure on the environment. Mushrooms are highly nutritious and environment friendly crops that carry numerous medicinal benefits. The intensive cultivations of edible mushrooms can often be affected by several insect-pests and diseases caused by fungi, bacteria, viruses, nematodes etc. that rather frequently cause dramatic production loss. The market price of edible mushrooms is also reduced due mould's contaminations. These infestations, infections and contaminations are facilitated by the particular environmental conditions under which mushroom cultivation is commonly carried out. There is not much bibliographic information related to such stresses of mushrooms and their management. The updated review presents a practical checklist of diseases and pests of the mushroom, providing useful information that may help different users.

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INTRODUCTION

According to current estimates, mushrooms constitute at least 14000 species worldwide and out of that 7000 and 2000 species are reported as edible and medicinal, respectively (Hawksworth, 1991). World mushroom production has increased more than 25-fold since 1990s. Five main genera constitute more than 85 per cent of the world's mushroom supply. *Agaricus bisporus* is the major genus contributing about 30 per cent of the world's cultivated mushrooms. *Pleurotus* with 5 to 6 cultivated species constitutes about 27 per cent of the world's output while *Lentinula edodes* contributes about 17 per cent. The other two genera, *Auricularia* and *Flammulina* are responsible for 6 per cent and 5 per cent of the volume, respectively (Royse, 2014). China is the main producer of edible mushrooms. In India mushroom production has increases in recent years with more than 70,000 MT in 2003-04 to over 113315 MT in 2010 (Singh *et al*., 2011). The increasing number of commercial farms cultivates mushrooms; growers have faced serious challenges caused by various biotic stresses

(Ro *et al.,* 2007). Among the biotic agents, fungi, bacteria, viruses, nematodes, insects, mites etc. cause damage to mushrooms directly or indirectly. Although careful farm management and extreme hygiene may prevent major attacks, some diseases are very difficult to control. Moreover, shelf-life quality is severely affected by diseases that are still asymptomatic at the time of harvest. This review presents a practical checklist of available diseases, insect-pests and moulds of mushrooms, providing useful synthetic information that may help different users. This study may be widely used by researchers, practitioners, professionals, handlers and others involved in mushroom enterprise.

Diseases:

Diseases are a major problem in mushroom cultivation; a high percentage of products are lost due to lower productivity, decrease in quality and shortened shelf life.

Fungal diseases:

There are many fungal pathogens of mushrooms, but only a few of them currently affect commercial mushroom farms. Some of these are true pathogens attacking the mushroom mycelium, while others can simply influence the mushroom mycelium growth. Fungal pathogens can either affect the quality of the product, reduce production, or both. But all of them reduce the total return of a crop, often significantly. They can be controlled or minimized through different prophylactic and curative measures.

Dry bubble or brown spot:

Verticillium fungicola is a major pathogen responsible for considerable yield losses of cultivated mushrooms (Gela, 1993). If it is left uncontrolled, disease can totally destroy a crop in 2-3 weeks (Fletcher *et al*., 1986). Thapa and Jandaik (1985) have recorded the incidence of dry bubble from 25-50 per cent at Solan and Kasauli and upto 15 per cent at Shimla and Chail (Sharma and Vijay, 1993). Numerous localized, light brown depressed spots appear on the mature sporophores. After coalition, these spots form irregular brown blotches with white fungal spore mass or grey mould fuzz covering the surface giving a dirty look. In advanced stages, a gray weft of mycelium and conidia frequently covered the surface of infected sporophores (Marlowe and Romaine, 1982). Diseased caps shrink in blotched area, turn leathery, dry and show cracks. Infected fruit bodies are malformed; onion shaped and become irregular and swollen mass of dry leathery tissue (Sharma, 1994). Pathogen grows best at higher temperature (27°C) (Fletcher *et al*., 1986). High humidity, lack of proper air circulation, delayed picking and temperature above 16°C favour its development and spread (Sohi, 1988). All the commercial strains are susceptible (Sharma, 1994). Use of sterilized casing soil, proper disposal of spent compost and proper hygiene and sanitation are essential to avoid primary infection (Sharma, 1994). Thirty-minute treatment with aerated steam at 60°C and 82°C, hindered spore germination and soil colonization by *V. malthousei* more than similar treatment at 98°C. Heat treatment of infected casing layer at 63°C for one hour completely prevented spore germination (Sharma *et al.,* 2007). Bhatt and Singh (2000) reported 5 bacterial isolates effective against *V. fungicola*. Few chemicals can be used for the control of dry bubble because the host is also sensitive to fungicides. Notably, the development of resistance of *V. fungicola* has been reported against the fungicides that are used to control dry bubble disease (Berendsen *et al.,* 2013). Good control of *V. fungicola* was achieved by spraying with Prochloraz manganese at 60g/100m^2 within 7 days of casing and subsequently at 2 weeks' intervals (Fletcher and Hims, 1981).

Wet bubble:

In India, this disease was reported for the first time in 1978 from Jammu and Kashmir (Kaul *et al*., 1978). Wet bubble of mushroom is incited by *Mycogone perniciosa* has also been reported to assume serious proportions in other major mushroom growing countries of the world (Forer *et al.,* 1974). Sharma and Kumar (2000) described the symptoms as short, curly, pure white fluffy mould growth of the pathogen on malformed mushrooms, which can be easily observed by naked eyes. Cross section of deformed sporophores without cottony growth showed black circular area just beneath the upper layer. Umar *et al.* (2000) described dramatic cytological changes as a result of infection when young (upto 6mm) pin heads were infected. Large, very irregular, nodular and tumorous fungal masses are formed and no differentiation or organogenesis of the cell mass takes place. The infection can be air-borne, water borne or

may be mechanically carried by mites and flies (Garcha, 1978). Hsu and Han (1981) reported water splash as an important factor for wet bubble spread on the beds. Bech *et al*. (1982) reported that spread through contact occurred readily during watering and especially harvesting. According to Van Zaayen and Rutigens (1981), thermal death point for *M. perniciosa* is 48°C. As the pathogen inflicts serious damage to the crop, various attempts have been made to manage the disease through various means. Zhang (1990) suggested three methods of prevention of wet bubble disease which include steam sterilization of mushroom beds, formaldehyde fumigation and fungicidal application. Another method like screening and selection of disease resistant strains should also be exploited. Geijn (1977) suggested the control of wet bubble disease by spraying the crop with Carbendazim, benomyl or Thiophanate methyl at 100-150 litre water immediately after casing. Basamid (Dazomet) and Vapam (Metham sodium) applied @100ppm to casing has also been reported very effective (Kim *et al*.,1978). Application of Carbendazim, Benamyl, Chlorothalonil, TBZ, Prochloraz manganese complex (Sportak 50 WP) into casing mixture have been reported very effective for the management of wet bubble by several workers (Sharma and Kumar, 2000).

Cobweb:

Cobweb caused by *Cladobotryum mycophilum* and is considered one of the most serious diseases for white button mushroom (Chakwiya *et al.*, 2015 and Zuo *et al.*, 2016). The prevalence of cobweb disease in commercial mushroom crops has been reported to vary between 6.8 and 28 per cent in Indian *A. bisporus* (Bhatt and Singh, 2002). The occurrence and severity of cobweb gradually increases from the first to the third flush (Carrasco *et al.*, 2016a). In cobweb, small, white patches appear on the casing soil and then spread to the nearest mushroom by a fine grey white mycelium that resembles a spider web. Cobweb mostly appears during the autumn and winter cycles (Carrasco *et al.,* 2016a). The pathogen is a soil inhabiting fungus and is normally introduced into the crop by soil contamination, spores, mycelium on crop debris or by farm workers. Spores are easily spread by air movement, workers hands, tools and clothing and by water splash (Sharma, 1994). Disease caused by *C. verticillatum* on *A. bitorquis* was favoured by RH 90 per cent and temperature of 25-30°C (Sharma, 1992). As soon as a primary cobweb outbreak is located over the casing or carpophores, it must be treated before sporulation, covering the infected area with thick damp paper to avoid the release of conidia and disease dispersion (Pyck and Grogan, 2015). Through disinfection of casing soil with live steam or sterilization of casing mixture at 50 °C for 4 hours effectively eliminates the pathogen. Regular cleaning, removal of cut mushroom stems and young half dead mushrooms after each break and controlling temperature and humidity helps in controlling the disease (Sharma, 1994). Annual disinfection of houses and surrounding areas with 2 per cent bordeaux mixture or with 5 per cent formalin solution or immediate spray after casing with benomyl @ 0.1% is useful for control to this disease (Sharma *et al.,* 2007). Recently, metrafenone (benzophenone) has been authorized for use in France to fight cobweb disease (FRAC, 2016). Recently, too, metrafenone obtained a temporary approval for use on mushroom crops in Spain (Carrasco *et al.*, 2016b and 2017).

Green mould or Trichoderma blotch :

It is one of the most common and destructive diseases in mushroom cultivation, mainly caused by different species of *Trichoderma, Penicillium* and *Aspergillus*. Among these moulds, *Trichoderma harzianum* induce significant quantitative and qualitative losses in the yield of *Agaricus bisporus, Pleurotus* spp., *Auricularia, Calocybe indica* and *Lentinula edodes* (Seaby, 1996). Jandaik and Guleria (1999) reported 5-46.87 per cent and 6.25-50.0 per cent yield losses due to *T. viride* and *T. harzianum*, respectively, under artificial inoculation conditions. In *Trichoderma blotch,* green patches appear in compost, spawn, on casing surface and also sometime on the mushroom surface. Mushrooms developing in or near this mycelium are brown, may crack and distort and the stipe peels. Some species induce brownish lesions/spots on caps which may cover the entire cap surface under congenial conditions (Park *et al.,* 2005). The appearance of green mould indicates poor quality compost, unhygienic cropping conditions and low compost pH. Green mould generally appears in compost rich in carbohydrates and deficient in nitrogen. Frequent use of formalin also tends to promote the development of green moulds (Sharma *et al*., 1999). High relative humidity accompanied by a low pH in the casing soil also promotes the development of *Trichoderma* spp. (Sharma *et al.,* 2007). Woo *et al.* (2004) observed that *Trichoderma* species are present at the initial phase of

substrate preparation, but later disappear with pasteurization. The mycelial growth of *Trichoderma* spp. is completely inhibited by pasteurization at 60°C for 10 h. The mycelial growth of green mold occurred at its maximum in 80 per cent of relative humidity conditions (Bellettini and Fiorda, 2016). Komon-Zelazowska *et al.* (2007) suggested the application of calcium hydroxide on the affected area. The substrate alkalization through addition of lime to increase pH to 7.5 is widely practiced to minimize the green mold. The use of fungicides Benomyl, Thiabendazole and Prochloraz was also reported to be effective (Gea *et al.,* 2005). Prochloraz was shown to be the most effective fungicide for the inhibition of mycelial growth in green molds. Prochloraz, Benomyl, Chlorothalonil and Propineb were found to inhibit spore germination (Bellettini *et al.,* 2018). Sharma and Vijay (1996) reported that weekly sprays of Mancozeb (0.2%) or Bavistin (0.1%) or treatment with zineb dust or Calcium hypochlorite have given effective control of the disease.

Bacterial diseases:

The bacterial pathogens induced varieties of symptoms like blotch, mummy, pit, drippy gill, soft rot, yellowing and immature browning but in India, bacterial diseases has been reported only on fruit bodies of *A. bisporus* and species of *Pleurotus* and *Auricularia*. The various bacterial diseases reported from India are discussed as under (Table 1).

Bacterial blotch:

In India, it was first reported in 1976 (Guleria, 1976). Bacterial blotch lesions develop on the surface of mushroom caps making the mushrooms unmarketable. The disease has been reported from almost all mushroom growing countries of the world. The disease causes 5 to 10 per cent losses in yield (Fermor, 1986 and Vantomme *et al*., 1989). In Australia, bacterial blotch is second in economic importance only to the virus disease complex (Nair, 1969) and substantial losses. The most characteristic symptom of bacterial blotch is the occurrence of dark brown areas of blotches on the surface of the cap. Severely affected mushrooms may be distorted and the caps may split where the blotch symptoms occur. The enlargement of the spots on the cap surface is dependent upon environmental conditions and is favoured by temperatures of at least 20°C together with the presence of water film. Casing and airborne dust are the primary means of introducing the blotch pathogen into a mushroom house. Manipulation of relative humidity, temperature, air velocity and air movements are of great significance in managing the disease. Temperature above 20°C and relative humidity of more than 85 per cent should be avoided. Additional ventilation and air circulation after watering can ensure the quick drying of mushrooms. Application of Terramycin 9 mg per square foot, Streptomycin (200 ppm), Oxytetracycline (300 ppm), Kasugamycin and Kanamycin has been found effective in managing the disease.

Bacterial yellowing:

Bacterial yellowing disease can cause the most severe damage in mushroom (Ferri *et al.,* 2007). The

Table 1: Bacterial diseases of edible cultivated mushrooms

Mushroom	Disease	Causal organism	Distribution	Reference
Agaricus bisporus	Bacterial blotch	*Pseudomonas tolaasii and P. fluorescens*	Worldwide	Fletcher *et al.* (1986)
	Mummy	*P. aeruginosa*	UK	Wuest and Zarkower (1991)
A. bitorquis	Bacterial blotch	*P. tolaasii*	Worldwide	Fletcher *et al.* (1986)
	Soft rot	*Bukholdria gladioli pv. agaricicola*	Worldwide	Guleria *et al.* (1987)
Oyster mushroom	Brown blotch	*P. tolaasii*	Japan	Fermor (1986)
(*Pleurotus* spp.)			Australia and	Ferri (1985)
			Netherlands	
	Yellow blotch	*P. agarici*	India, USA	Jandiak *et al.* (1993)
Other mushrooms				
Volvariella spp.	Bacterial rot	*Pseudomonas* sp.	India and	Fermor (1986)
			Indonesia	
Lentinus edodes	Browning	*P. fluorescens*	Japan	Komatsu and Goto (1974)
Flammulina velutipes	Brown soft rot	*Erwinia* sp.	Japan	Phawicit (1985)

disease is characterized by a yellow discoloration of the pileus and hydropic, often elongated and coalescing areas on the entire stem. (Bruno *et al.,* 2013). *Pseudomonas agarici* and *P. reactans* are reported as the most likely causal agents of yellowing in both *P. eryngii* and *P. ostreatus* (Iacobellis and Lavermicocca,1990). *P. reactans* belong to the V group of fluorescent *Pseudomonas* and is considered to be saprophytic bacteria inhabiting the mush-room hyphosphere (Munsch and Alatossava, 2002). According to Bruno *et al.* (2013), other bacterial species have been isolated from symptomatic basidiomata. Bessette *et al.* (1985) reported that the yellow blotch in *P. ostreatus* caused by *P. agarici* formed a clean yellow fluid on the surface of the cluster at first and then deformed with an increase in severity. The stipes tended to recurve near the base and the sporocarp was upright. Much research has been done to figure out an adequate method to prevent or control this disease. Controls, such as lowering relative air humidity, and watering with low concentration of chlorine solution are currently the most commonly utilized chemicals for blotch disease control. When mushrooms remain wet, however, chlorine has little effect since the bacterial population reproduces at a rate that neutralizes the effect of the oxidizing agent (Geels *et al.,* 1988). Several other disinfectants and antibiotics, such as chloramine T and bronopol, essential oils and Kasugamycin, have also been tried for their ability to control bacterial blotch disease (Geels, 1995 and Yang *et al.,* 2011). According to Bruno *et al.* (2013), acetic acid at 87.4 and 69.9 mM may be used as antibacterial compound.

Bacterial soft rot :

The gram-negative bacterium *Pantoea* spp. has been reported as a causal agent of soft rot disease with symptoms of water-soaked lesions on the stipes and pileus of *P. eryngii* (Kim *et al.,* 2007). The typical symptoms of soft rot disease include a dark brown water drop in the early stages of infection, followed by the development of water-soaked lesions on the stipe and cap of mushrooms within 8 days after the mushrooms are transferred to the cultivation room. The lesions expand gradually and constitute a viscous, mucus-like fluid, finally leading to a mushy soft rot accompanied by an offensive odor during growth (Rodriguez-Estrada and Royse, 2007). Liu *et al.* (2013) isolated strains belonging to *Pantoea beijingensis* (growth occurs at 10-37°C) from lesions on the fruiting body of *P. eryngii* exhibiting symptoms of water-soaked lesions and soft rot in the stipes and pilei. Compounds containing active chlorine are, at present, the most commonly utilized chemicals for bacterial disease control. Watering with concentrations at 175 ppm active chlorine were effective for the reduction of soft rot disease of *P. eryngii* without affecting mushroom yield (Liu *et al.,* 2013).

Stipe necrosis :

E. americana was identified as the causal agent of internal stipe necrosis on symptomatic samples collected from mushroom farms. Reyes *et al.* (2004) demonstrated the predominance of *E. americana* in biota of retail fresh *P. ostreatus*. The symptoms of internal stipe necrosis appear as a variable browning reaction in the center of the mushroom stipe Inglis *et al.* (1996). Examined in longitudinal section, the brown tissue extends from the base of the stalk to the cap, but rarely penetrates the cap tissue. Affected mushrooms may be wet in appearance, but frequently, at harvest; the brown tissue is dry and has completely collapsed, leaving a hollow center. In all cases, symptoms are visible only at harvest. The occurrence of internal stipe necrosis disease has occasionally been associated with water-logging of the mushroom stalks at an early development stage and it is, therefore, important to maintain good evaporation from the bed surface at all times (Fletcher and Gaze, 2008). In *P. ostreatus*, symptoms consisted of soft rot and mild browning of the tissues. According to González *et al.* (2012), *E. americana* is pathogenic in *P. eryngii*, although its presence was not dominant in the analyzed samples, being isolated in only 10 per cent of them. However, Reyes *et al.* (2004) reported that the presence of this bacterium was high in commercial products. These results indicate that the pathogen is found in crops and increases during storage.

Viral diseases:

It also named as La France disease, brown disease, watery stipe and X-disease. Virus disease in mushroom has been reported from India by Tewari and Singh (1985) and has also been reported from several countries. The viral diseases are not detectable during spawn – run stage; the initiation of pinheads is inhibited and vigour of mycelium severely reduced; yield is drastically reduced,

mushrooms appear with distorted shape, delay occurs in appearance of first flush, sporophores with elongated stem and small caps giving drum stick like appearance and tilted towards one side appear, mushrooms appear in patches, premature opening of veils, watery stipe and streaking in the stipe. In India, virions measuring 29nm and 35 nm in diameter have been found associated with a virus disease of button mushroom. Virus like particles measuring 29nm in diameter has also been reported in button mushroom as revealed by immunosorbent electron-microscopy (Goltapeh and Kapoor, 1990). Mycoviruses typically possess double stranded RNA (ds RNA) genomes, the discovery of discrete ds RNA molecules in diseased tissues constitutes the most convincing evidence for the viral etiology of La France disease (Wach *et al*., 1987). It was also reported that a viral complex (Sonnenberg and Griensven, 1991 and Romaine and Schlagnhaufer, 1991) involving a ss RNA virus and unrelated ds RNA virus (es) plays a role in etiology of La France disease. Mushroom viruses are transmitted through mycelium. This is the most common method of transmission and has been confirmed by several workers (Dieleman-van Zaayen and Temmink, 1986). The mushroom viruses can be reduced through heat therapy. Hybrid strains can anastomose with both white and off-white strains and therefore, their widespread culture may reduce the effectiveness of strain alteration as a means of virus control (Fletcher *et al*., 1989). Owing to the lack of useful resistance with the species, control of the disease is based largely on the use of hygienic practices directed at the elimination of diseased mycelium and basidiospores from the production (Van Zaayen, 1976). Dieleman-van Zaayen and Temmink (1986) has suggested various prophylactic and curative approaches to reduce the spread of mushroom virus diseases.

Nematodes:

Nematodes are the most dangerous pest of mushroom and their presence leads to very poor yields or total crop failures. Button mushrooms are generally highly susceptible to nematode infection while oyster mushrooms are relatively resistant (Singh and Sharma, 2016). A disease that causes knots on the gills of the oyster mushroom *P. ostreatus.* Nematodes inhabit and lay many eggs inside the gill knots. Three nematode species, namely *Aphelenchoides composticola*, *Aphelenchus avenae* and *Ditylenchus myceliophagus* are affecting to mushroom (Tsuda *et al.,* 1996). The parasitic nematodes use their stylet to pierce the mycelial cell and inject digestive juices. Compost infested with nematodes has a characteristic appearance: soggy, sour smelling, and depressed. Saprophytic nematodes, often referred to as "free-living," now are more commonly associated with mushroom farming than the parasitic species. They characterize poorly prepared compost and/ or casing and cause severe deterioration of mycelium in their own right. Since the use of chemicals for the management of nematodes has many constraints, only alternative left is to exploite biological means. Fungus *A. irregularis,* is highly effective against *A. composticola*. Incorporation of dried leaves of *Azadirachta indica, Cannabis sativa, Eucalyptus tereticornis* and *Ricinus communis* at 3 kg/100 kg of dry wheat straw, enhanced the population of thermophilic fungi, mesophilic antibiotic producing fungi and at the same time reduced the population of *A. composticola* below economic injury level. Incorporation of *Neem* cake @ 5% on w/w basis of compost at spawning has been reported to hamper the multiplication of *A. compostiocola.* Use of heat is the most successful method of nematode control in mushroom cultivation. It is recommended that to make compost nematodes free, air and bed temperature in the pasteurization room must be maintained at 60^0C at least for 2 hours and cook out of mushroom house at 70^0C for 5-6 hours or 80^0C for 30-60 minutes is necessary. Kaneko (1983) controlled this disease by covering the logs used to grow mushrooms with a 1 mm mesh screen net; therefore, he suggested that an insect larger than 1 mm must take part in the transmission of the disease. Thionazin at the rate of 80 ppm is the only recommended nematicide for the control of myceliophagous nematodes without residual toxicity (Singh and Sharma, 2016). However, some of the chemicals, which can be used during composting itself are effective in checking nematode population especially long method of composting. Dichlorvos (0.04%) under polythene cover for 3-4 days was found to be most effective for control of *A. composticola* and *Rhabditis* sp. For nematode control, all soils should be sterilized by stem (70-75 ºC for 6 hrs) or formaldehyde-40 @ 5% solution.

Competitor moulds:

Different fungi occurring in the substrate and

competing with mushroom mycelium for space and nutrition (Das and Suharban, 1991). In addition to these moulds being competitive some have been shown to produce metabolites which directly inhibit the growth of mushroom mycelium. There are following competitor moulds occurred in mushroom cultivation.

False truffle :

It is caused by *Diehliomyces microsporus*. In India, it causing serious losses to mushroom crops when the compost temperature in the trays reached beyond 22-24 °C. The natural incidence of false truffle in *A. bisporus* grown under natural climatic conditions has been reported from 1-80 per cent (Sharma and Vijay, 1996). In Himachal Pradesh, it was occurred with 66-88 per cent incidence and cause 58-80 per cent yield loss (Sharma *et al.,* 2007). The colour of the fluffy mycelium of this competitor is white to start with and turns a creamy yellow at a later stage. It appears as small wefts of white cream colored mycelium in compost and casing soil, usually more conspicuous in the layer where compost and casing mixture meet and also on casing. At maturity they become pink, dry and reddish and finally disintegrating into a powdery mass emitting chlorine like odour. The fungus does not allow the mushroom mycelium to grow and compost turns dull brown. The spawn in affected patches turns soggy and disappears (Singh *et al.,* 2011). Ascopore germination upto 70 per cent has been recorded at 27°C after giving heat stimulus at 40-50°C for half an hour (Sharma, 1998). The major sources of infection are casing soil and surviving ascospores/mycelium in wooden trays from the previous crops. Ascospores can survive for a periods of 5 years in soil and spent compost and mycelium for 6 months (Sharma, 1998) and thus serve as the major source of primary inoculum. Optimum growth of the fungus has been recorded at 26-28°C. For control to this competitor, compost should be prepared on a concrete floor and never on uncovered soil. Because during composting there is rise in temperature which activates the ascospores present in the soil. Pasteurization and conditioning of the compost should be carried out carefully. Maszkiewiez and Szudyga (1999) observed that pasteurization of compost under optimum condition completely eliminated the false truffle inoculum in the compost. Young truffles must be picked and buried before the fruit bodies turn brown and spores are ripe. Woodwork, trays or side-boards of shelf-beds should be treated with a solution of sodium-pentachlorophenolate at the end of the crop which was infected with the truffle disease. Air-drying of wood-work for 2-3 months may also eradicate the pathogen. Good cooking out (compost temperature 70°C for 12h.) at the end of the crop should be carried out which will kill mycelium and spores of the pathogen in the compost (Sharma, 1998).

Olive green mould:

It is caused by *Chaetomium olivaceum* and *C. globosum*. The first evidence of the occurrence of *C. olivaceum* in India was provided by Gupta *et al*., (1975). Another species, *C. globosum,* was later reported from mushroom farms in HP, Delhi and Mussorie (Thapa *et al*., 1979). Yield losses ranging from 12.8-53.65 per cent have been reported in *A. bisporus* (Sharma and Vijay, 1996). The earliest signs of the fungus consist of an inconspicuous greyish-white fine mycelium in the compost or a fine aerial growth on the compost surface 10 days after spawning. Frequently initial spawn growth is delayed and reduced. By late spawn run, fruiting structures that look like gray-green cockle-burns-1/16 inch in diameter, develop on straw in isolated spots of the affected compost (Singh *et al.,* 2011). The infection usually comes through air, compost and casing soil. It appears due to defective composting in phase-II because of improper pasteurization accompained by high temperatures in the absence of adequate fresh air. Improper stacking of the compost trays in the pasteurization room which do not allow proper circulation of the air or overfilling of the room causes intensive condensation when wet steam is introduced; result in non-selective compost which harbors *Chaetomium* and other moulds (Sharma, 1992). For control to this disease, the fermentation period of the compost should not be too short. Higher temperatures (above 60°C) for longer time should be avoided. Large number of fungicides including Benomyl, Thiophanate methyl, TBZ, Dithane Z-78, Dithane M-45, Thiram and Captan have been found effective under *in-vitro* conditions (Thapa *et al*., 1979) and sprays of Dithane Z-78 (0.2%) have been recommended for checking the secondary spread (Sohi, 1988).

Brown plaster mould:

This is caued by *Papulaspora byssina* and it was

first reported on horse dung compost from Missouri (Sharma *et al.,* 2007). This mould has also been reported to cause complete crop failure in oyster mushrooms in Kasuali, HP (Dar and Seth, 1981). This mould has invariably been isolated from different compost and casing samples collected from mushroom farms in northern India and the incidence of the disease has been recorded from 5 to 9 per cent. (Sharma and Vijay, 1996). Loss in number and weight of fruit bodies as a result of artificial inoculation of the mould has been found 7.7-53.5 per cent and 3.0-50.7 per cent, respectively (Sharma and Vijay, 1993). It is first noticed as whitish mycelial growth on the exposed surface of compost and casing soil in trays as well as on sides in bags due to moisture condensation. This develops further into large dense patches gradually changing colour through shades of tan, light brown to cinnamon brown; ultimately becoming rust coloured. No mushroom mycelium grows on places where plaster mould occurs (Singh *et al.,* 2011) Primary infection comes through air-borne bulbils or containers, compost and casing soil and workers. Its development is favoured by wet, soggy and wrongly prepared compost. Higher temperature during spawn run and cropping favours the disease development. In wet, greasy compost which had not received enough oxygen during fermentation and many of amines, development of the disease is greatly favoured. Addition of less quantity of gypsum and more greasiness favour the disease development (Singh *et al.,* 2011). For successful control of this pathogen, the composting should be carried out carefully, using sufficient gypsum and not too much water. Peak heating should be of sufficient duration and at proper temperatures. The compost should not be too wet before or after peak heating. Munjal and Seth (1974) recommended localized treatment of infected patches with 2 per cent formalin while. Seth and Shandilya (1978) recommended 4 per cent formalin for its control. Large number of fungicides namely, benomyl, carbendazim, thiophanate methyl, vitavax, daconil, MBC, dithane Z-78, dithane M-45, captan, thiram and copper fungicides have been screened under *in vivo* and *in vitro* conditions by various workers (Dar and Seth, 1981).

Yellow mould :

It is caused by different types of fungi like *Myceliophthora lutea, Chrysosporium luteum* and *C. sulphureum.* All these fungi produce yellow mycelial growth in the compost (Kaul *et al.*, 1978 and Garcha *et al.*, 1987). In Himachal Pradesh, it is reported that it caused 5-20 per cent loss on the yield of button mushrooms under natural conditions (Seth and Bhardwaj, 1989). In India, *M. lutea* has been reported to induce yellow brown corky mycelial layer at the interphase of compost and casing which is difficult to detect during the impregnation of casing layer by the spawn and even during the first break. It becomes apparent when it develops its stroma like morphology and mushroom production is severely inhibited (Singh *et al.,* 2011). The major sources of primary inoculum are air, chicken manure, spent compost and defectively sterilized wooden trays (Seth and Bhardwaj, 1989).The secondary spread is mainly through mites followed by flies, water splashes, picking and tools. The fungus survives easily through thick walled chlamydospores. Disease severity is generally more at 70 per cent moisture content of the compost and 19-20°C temperature. It can be controlled by proper pasteurization of the casing mixture. Fungus does not survive the exposure for 6 hrs at 51°C or 4 hrs at 54°C. Benomyl (400-500ppm) and blitox (400ppm) sprays have been found effective to control the disease and increase the yield (Seth and Bhardwaj, 1989).

Sepedonium yellow mould:

It is caused by *Sepedonium* and its incidence has been reported by vary from 5-20 per cent with insignificant reduction in yield except in extreme cases (Thapa *et al.*, 1991). Bhatt and Singh (2000) have recorded 1.6 to 8 per cent incidence of yellow mould in Haryana and UP States and 32 to 64 per cent loss in yield under artificial inoculation conditions. This mould is mainly observed in the compost and is initially white in colour turning to yellow or tan at maturity. It is generally present in the lower layers of the compost or at bottom of the cropping bags. Various types of distortions in fruit bodies are commonly observed, probably due to the production of volatile substances or toxins. These toxins inhibit the spawn and ultimately mushroom mycelium disappears from the compost (Singh *et al.,* 2011). Primary source of inculum are probably, soil, spent compost, air or improperly sterilized wooden trays. Higher N content, especially in the form of chicken manure, have been reported to favour the mould development (Vijay *et al.,* 1993). Its appearance in the lower layers of the compost has been linked with more

wetness. Sharma and Sharma (2000) have reported very high population of *Sepedonium* spp. in 3-12 months old chicken manure which may serve as the primary source of inoculum in long method of compost. Preventing the entry of spores during spawning and spawn-running by installing high-efficiency air filters are essential. Incorporation of 0.5 per cent Carbendazim in compost and sterilizing the chicken manure (for long method of composting) with 2 per cent formalin and 0.5 per cent Carbendazim has given good results (Vijay *et al*., 1993).

Ink caps or weed mushroom:

It is caused by *Coprinus* spp. which appearing as inky caps. The appearance of inky caps during spawn run is commonly observed on the mushroom beds in northern India (Garcha, 1984 and Sohi, 1988). *C. fimetarius* resulted in 20.14-94.4 per cent reduction in the number of fruit bodies and 14.68 to 94.43 per cent reduction in the weight of fruit bodies under artificial inoculation conditions (Sharma, 1992). Ink caps appear in the compost during spawn run or newly cased beds and outside the manure piles during fermentation. They are slender, bell-shaped mushrooms. Cream coloured at first, blueish-black later and are usually covered with scales. This fungus sometimes grows in clusters in beds and has a long sturdy stem which often reaches deep into the compost layer. Several days after their appearance ink caps decay and form a blackish slimy mass due to auto-digestion. The infection generally comes through unpasteurized or partially pasteurized compost or casing soil or air. Ink caps appear if the compost contains too much N, so if too much chicken manure is used, or if the peak heating period is too short. These are, therefore, genuine indicator moulds which are benefited from insufficiently converted N containing constituents like NH_3. Ink caps can also develop if insufficient gypsum is added to the compost or if peak heating has taken place at too low a temperature or if the compost is too wet and poor in texture. The large masses of spores released through inking of the caps can very easily infect freshly prepared compost. Use properly pasteurized compost and casing soil. Avoid excessive watering. Rogue out young fruit bodies of the weed fungus to avoid its further spread.

Cinnamon or brown mould :

It is caused by *Chromelosporium fulva,* its occurrence has been reported in mushroom beds from Jammu and Kashmir (Kaul *et al*., 1978) and Punjab (Garcha *et al*., 1987) and different parts of HP (Sohi, 1988). The colour of *C. fulva* is appeared as cinnamon brown mould, its colour ranges from yellow gold to golden brown to cinnamon brown. The mould first appears as large circular patches of white aerial mycelium on the compost or casing. Within few days the spores are formed and the colour changes from white to light yellow or to light golden brown. Soil, casing mixture and damp wood are the sources of primary inoculum. Inoculum can blow through open doors or splash from floor during cleaning. The spores of the fungus are easily air-borne. Over pasteurized compost, over-heated patches during spawn run, high moisture content of the compost and excess of ammonia present in the compost favour the disease development. Casing soil should not be made completely sterile by steam or formaldehyde. Newly cased beds should be sprayed with Dithane Z-78 and maintain proper moisture content in casing layer.

Lipstick mould :

This disease is caused by *Sporendonema purpurescens* and has been reported from mushroom farms in Punjab (Garcha *et al*.,1987) and HP (Sohi, 1988). The disease first appears in spawned compost as a white crystalline-like mould. As the spore of the mould mature, the colour changes from white to pink, to cherry red and then to dull orange or buff. White mycelial growth is more in loose areas of casing and can colonize well conditioned compost. In crops where there is a serious virus disease, lipstick mould usually occurs as a secondary disease. Soil, casing mixture and spent compost are the sources of primary inoculum. It is further disseminated by water splashes or pickers. The mould is reported to be associated with the use of chicken manure in the compost formula; the litter is said to carry the lipstick fungus. Good hygiene is essential. Good pasteurization and conditioning of the compost will eliminate the pathogen.

Lilliputia mould :

It is caused by *Lilliputia rufula* (Berk and Br.) Hughes. This competitor mould has been reported from HP and Delhi (Seth and Munjal, 1981) with an incidence of 1-40 per cent during 1975-1979, maximum being in Chail (HP). It seriously restricts the spawn spread in

the compost resulting in poor yields. The sexual stage has been identified as *Gliocladium prolificum* Bainer. Chicken manure, horse manure as well as casing mixture are the primary sources of infection. Mycelium is viable upto 3 months (at 10°C) and cleistothecia upto 9 months under room temperature. Use of dithane Z-78 at 20ppm concentration has been recommended for the control of the mould (Seth and Munjal, 1981).

Pink mould :

Pink mould is caused by *Cephalothecium roseum* Corda. This mould has been observed in J and K and Chail and Solan in HP as a white growth on the casing soil which turns pink in due course (Seth, 1977 and Sohi, 1988). Yield loss upto 90 per cent or even complete crop failures have also been recorded. Hyphae are septate and branched. Conidiophores erect, usually branched and slightly swollen at the tip. Conidia acrogenous, single, pear shaped, 2-celled, the apical cell being larger, hyaline to pink, 11-18x7.5-9.5m. Infection generally comes through air. Mould can be checked by spraying twice thiram or captan (0.04%) on casing soil at 10 day intervals (Guleria and Seth, 1977).

Oedocephalum mould :

It is caused by *Oedocephalum fimetarium*. This is a common mould observed on mushroom beds in HP and incidence upto 60 per cent has been observed in a farm at Solan. Artificial inoculation of casing layer with *O. fimetarium* @ 5g inoculum per 10kg compost bag has reduced the number and weight of fruiting bodies by 19.9 per cent and 11.63 per cent, respectively (Sharma, 1991 and Sharma and Vijay, 1993). The mould forms irregular, light silver gray patches on the compost surface during cool down before spawning. After spawning, the mould is light gray but changes to dark tan or light brown as the spore mature. Similar growth is also recorded on casing layer. Conidiophores of the fungus are erect with a spherical cluster of large spores at its tip end. *Oedocephalum* sp. in compost indicates that ammonia and amines were not completely eliminated during pasteurization and conditioning. Spraying or swabbing locally with 2 per cent formalin controls the mould.

White plaster mould :

This mould is caused by *Scopulariopsis fimicola.* This disease has been reported to occur commonly in different parts of India (Bhardwaj *et al*., 1987) causing about 37 per cent loss in yield. The disease appears as white patches on the compost or casing soil. These patches or mycelial mats may be more than 50cm under favourable conditions. The white growth changes to light pink after a week of the formation of the spot. Spawn run is reduced significantly and under severe conditions complete crop failure are also recorded. The pathogen is favored by over composted compost which still conditions and containers used for retains the smell of ammonia and cultivation. has high pH (more than 8). Proper composting and addition of optimum quantities of water and gypsum are recommended. Sprays of benomyl (0.1%) and local application of formalin (4%) after the removal of the mat are helpful in controlling the disease.

Insect-pests, mites and other minor pests:

Mushroom are affected by several insect-pests and mites (Bellettini and Fiorda, 2016 and Rosa, 2007 and Bellettini *et al.,* 2015).

Flies :

The two major classes are flies in the family Sciaridae, primarily *Lycoriella* sp. and *Bradysia* sp. (Castilho *et al.,* 2009) and the Phorid fly *Megaselia* sp. are prevalent worldwide. The sciarids are most frequently a problem in production systems where Phase II compost is transferred to mushroom growing houses before it is colonized by mycelium. Sciarid flies (*Lycoriella mali*) are the major insect pest of mushrooms. It found naturally in cool shaded woods and areas of dense vegetation. can result in yield loss through degradation of the compost and casing and destruction of mycelium and fruit body primordia in the casing. In severe infestations, larvae can tunnel up into the stipe, resulting in the condition referred to as "black stem," which renders the mushrooms unmarketable. The potential for crop damage through reduced yield and quality is significant with this pest. Phorids more commonly invade compost that is already colonized by *Agaricus* mycelia (Jess and Schweizer, 2009). Infestations of fungus gnat can reduce yield by 15-22kg. m^2 (Nair and Clift, 1993). The larvae of fungus gnats feed on compost, damage developing spawn and burrow through mushrooms leaving holes that directly damage the product (White, 1985). A Phorid fly (*Megaselia halterata*) is the second major pest of

mushroom. They appear stockier than sciarids and are very active, running and hopping erratically. They prefer warmer air temperatures and drier conditions in the substrate. Phorid larvae feed only on mycelium and graze selectively. Cecid flies (*Heteropeza pygmaea*) larvae feed on the mycelium as well as on the stipe and gills of mature mushrooms. Cecid larvae have the potential of feeding on mycelium within wooden structures inside growing rooms. Because the wood offers some insulation from the heat of cookouts, they may survive the high temperatures and infest the next crop. Direct treatment of wood with insecticides and fungicides may be necessary to reduce between-crop survivors if there are high populations of cecid on the farm. To protect crops, growers may incorporate insecticides into compost and/ or peat applied at casing. In many countries, diazinon is (or was) incorporated at compost manufacture to control fungus gnats. A dose of 200-500ppm in compost is sufficient to control phorids, while 1,000 to 1,500 ppm may be needed to control sciarids (Navarro *et al.,* 2017). Moreover, if insecticides are applied at casing, this can allow insect populations to develop and damage mycelia, during the 14–19 days following pasteurisation. Residue levels declined slightly in second and third flushes (Navarro *et al.,*2017). Organophosphates such as diazinon can potentially delay flushing and reduce yield by 4 to 14 per cent (Jess and Kilpatrick, 2000). However, research results on this effect are mixed, with some researchers finding no effect (Navarro *et al.,* 2017). The insecticides diflubenzuron and chlorpyrifos can also provide control, but may reduce mushroom yield by 20 to 69 per cent (Brar and Sandhu, 1991). A 2009 study at the MLMRU by Shamshad *et al.* (2009) tested a number of different insecticides against fungus gnats. Triflumuron incorporated into the casing was most effective at reducing fly emergence from both compost and casing. A Chinese study found that Bt could reduce sciarid fly populations by 74 to 99 per cent. However, this work was done on a very small scale (Ying *et al.,* 2014). In contrast, Jess and Kilpatrick (2000) found that Bt was ineffective against sciarids. Flies feed mushroom nutients from fruiting bodies and are capable of carrying fungal contamination, bacteria diseases and mites (O'Connor and Keil, 2005). *Lycoriella mali* Fitch (Family *Sciaridae*) is the major pest species of commercial mushrooms throughout the world (Choo *et al.,* 2001). Flies, especially in their immature stage (larvae), perforate the stipe and pileus of mushrooms, opening inside galleries, is causing its overall depreciation (Bellettini and Fiorda, 2016). For the control of flies in growth rooms, the most common techniques are tapes and traps. Use of pyrethroids chemicals is also useful (Eira *et al.,* 1997). The use of alcoholic and water sticky traps can be a valuable tool for the grower and a complement to other methods used for the control and prevention of pests in the crop. Sticky traps consist of white or yellow-coated plastic plates with slow drying glue. These traps can also be in the form of double-sided tape, used for the same purpose as the plate. The sticky traps should be replaced after saturation by dead insects. The traps must be filled with 80 per cent alcohol and hung along the crop (Bellettini *et al.,* 2015).

Mites:

Cultivated mushrooms are generally infested with mites belonging to Acaridae, Pyemotidae, Eupodidae, Ascidae, Digamsellidae, Scutacardiae, Tydeidae and Macrochelidae (Cha, 2004 and Rosa, 2007). *Tarsonemus* spp. and *Histiostoma* spp. are major mushroom damaging mites. They develop very fast under high humidity conditions (above 90%) and temperature (25-30^{o}C). The first signals are webs formed between the cultivation shelves, mycelium and fruit body where bacteria and fungi can come in. Mites feed on mycelia and fruiting bodies, causing yield loss and a decrease in mushroom quality. Mites carry pathogens and nematodes, sometimes causing itchy rashes among growers (Cha, 2004). For their control, smoke extract can be used over the compound in colonization. An infusion of coriander leaves can also be used (Rosa, 2007). Cultivated mushrooms are infested by several groups of mites. Fifty-four species of mites have been reported from various parts of the world, of which 16 species have been found to be economically important. Damage caused by the mites vary with the species. *T. dimidiatus* hollows out tiny buttons while in large mushrooms it makes cavities of various sizes on stalk and caps. *T. berlesei, T. mycophagus* and *T. longior* make holes on caps. *Caloglyphus keameri* and *Oppia nitens* make deep pits on stalk and cap while in some cases buttons are completely hollowed out after tunneling within the stipe. *Tyrophagus putrescentiae* feeds on mycelium and sporophore resulting in small irregular pits on stalk and caps. *Pygmephorus* sp. (Red pepper mite) feeds on mycelium below the casing layer. The red pepper mite

feed on weed moulds. Their presence thus, indicate poor compost infested with weed fungi like *Trichoderma.* These mites are also known to cause allergic reactions to humans. The measures helpful against mites are proper pasteurization of compost and casing material, proper hygiene and sanitation, disinfection of mushroom houses by spraying 0.1 per cent dicofol, burning sulfur in the empty rooms @ 200-250 g/1000 cu. ft., cooking out at 70^0C for 1-2 hours, after each crop, sterilization of empty trays, disposal of spent compost in pits at least one mile away from mushroom house.

Minor pests :

Beetles can affect the edible mushroom cultivation from the beginning of fruiting. These insects lay their eggs inside the mushroom and when hatched can feed on its nutrients. *Cyuodes bifacies* is a pest of the *P. ostreatus* (Gnaneswaran and Wijayagunasekara, 1996) and it was reported that some mushroom growers had to close down the industry. For their control, a pepper mash or Bordeaux mixture can be used with adhesive for beetle immobilization, enabling the deposit of their eggs in the mushroom tissues (Bellettini and Fiorda, 2016). Termites represent a constant danger during growing season, as many grow-room structures are made of wood. All termite mounds near the growing room must be eliminated or controlled. For their control, gasoline or mothballs with insecticide are used around the cultivation area (Oei and Nieuwenhuijzen, 2005). Molluscs such as slugs, snails and conch can be pests in mushroom cultivation because they are fed with mushrooms at the beginning of shaping. The control is performed with quicklime, inducing dehydration of mollusks (Rosa, 2007). Rodents feed directly from mushrooms. For control to rodents, calcined gypsum can be used along with wheat flour or boric acid-based bait (Eira *et al.,* 1997).

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