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Review on the Fungal Diseases of Mushroom: Etiology, Symptoms and Control

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A B S T R A C T
Mushroom, which is a fungus of higher class, is susceptible to many microbial attacks caused by fungi, bacteria and viruses due to which mushroom farms are being subjected to heavy losses worldwide. Among the various causes, fungus are the main factors that are liable to infect mushroom with diseases such as green mould, wet bubble, dry bubble, cobweb disease and brown mould. As far as the signs and symptoms are concerned, each of them appears with distinct types. As a remedy to these fungal constraints, several management approaches can be applied including chemical and biological control along with appropriate cultural practices.
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Keywords*: Bio-control, Chemicals, Cultural practices, Distinct, Fungal, Losses, Susceptible.*

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INTRODUCTION
The contribution of agriculture in national GDP of Nepal is 27.08 [1]. It is the main source of nutrition for the world population[2] and mushroom production aids largely to this. Mushroom is a fleshy, conspicuous umbrella shaped fruiting body arising from a group of mycelium buried in a substratum [3]. They are higher fungus, which transform dead and decaying organic matters into organic acids, carbon dioxide, and biomass [4]. Mushroom as fungi have been used by humans for many years, of which the commonly which have been used by humans for many years, of which the commonly cultivated ones include *Agaricus, Lentinus, Pleurotus* and *Volvariella* [5]. Several diseases of cultivated mushrooms are caused by many species of bacteria and viruses [6]. Fungal pathogens such as *Lecanicillium (Verticillium) fungicola, Mycogone perniciosa, Cladobotryum (Dactylium)* spp. and *Trichoderma* spp. affects the cultivated mushroom causing serious fungal diseases:, dry and wet bubble, cobweb disease and green mould, respectively [7;8]. Mushroom production represents the recycling of agro-wastes [9] and is adversely affected by a number of biotic and abiotic factors [10]. Biotic factors associated with yield reduction in the yield of mushrooms, fungal diseases significantly affect mushroom production and yield. Food insecurity is the present days emerging problem [11]. The diseases are a major threat to the mushroom industries causing worth millions of losses as these diseases may go up to 100% [5]. In the present scenario of the economy, it has opened up new vistas of export earnings[9]. Once the disease is introduced in the farm it can be carried out by the different agencies like air, water, machines and workers [12]. The study on etiology, symptoms and control of mushroom fungal diseases becomes a necessity after realizing the drastic damage they cause in the yield and productivity of the mushroom crop.

MATERIALS AND METHODS
Mainly secondary information from different publication and market hub information were the main sources of information for this paper. Secondary data collected through different sources were used and descriptive analysis was done based on the available information.

Green Mould
Etiology
Globally *Trichoderma* species leading to a devastating disease named green mould is a serious problem to mushroom producing industries[13]. It is the most devastating disease, accounting for losses that may range between 60% and 100% [14;15]. The condition got more severe after green mold became an epidemic disease in Northern Ireland in 1985, followed by outbreaks in Ireland (1986), England and Scotland (1987), the Netherlands (1994), France (1997), and Spain (1998)[16]. It is caused by Trichoderma spp. which are are soil inhabiting filamentous fungi and are worldwide in distribution. Certain members of this genus can also cause contamination in humans [17]. The causative agents were originally known as biotypes Th2 and Th4 of Trichoderma harzianum [18], but later they were introduced as the new species *Trichoderma aggressivum f. europaeum* and *f. aggressivum*, respectively [19]. *Trichoderma agressivum*

causing Green mould disease earlier was majorly described for Agaricus bisporous . However, in recent years the oyster types are also greatly affected[17].

Trichoderma species are found at the initial phase of substrate preparation, then they disappear with pasteurization. But they can reappear in the substrate anytime afterwards either after spawning (inoculation with Pleurotus) or during spawn-run (incubation phase) or at the harvesting stages [20] and [21].

This disease is spreading fast so there is a greater need of a rapid method of detection of the pathogens, so that it can be controlled accurately [16]. A polymerase chain reaction (PCR)-based technique for the rapid and specific detection Trichoderma species has been developed [22].

Symptoms

Trichoderma spp. leads to a considerable depletion of growth of mycelium and fruiting bodies of mushroom which causes loss in the yield substantially[23].

It is characterized by dense white mycelial growth which is followed by the extensive green sporulation of the fungus. Spawn runs give way for the large patches of green *Trichoderma sporulation* [14].

Control

Disease control includes a series of preventive measures in mushroom farms like strict hygiene and treatments with disinfectants [24]. Chemical fungicide treatment and application of antagonistic bacteria, have been shown to control the disease effectively[22]. To prevent and control the disease, the influence of various factors, such as temperature, pH and substrate moisture content should be properly checked, therefore it is important to control in efficient manner [25]. To prevent and control the disease, the influence of various factors, such as temperature, pH and substrate moisture content should be properly checked. The disease control is done mostly by the fungicide's application. Studies on fungicide efficacy on cultivated mushrooms by agrochemical companies are rare, only few fungicides have been officially recommended [26]. Chemicals named Pro- chloraz are used in the European Union, as well as chlorothalonil and thiabendazol in North America [27;28]. The most effective fungicide for the control is pro-chloraz, which was found to be effective also against the main fungal pathogens [27]. Toxicity of metrafenone was also satisfactory and can work as a potential solution for the control of green mold diseases in mushroom farms [24].

Dry Bubble

Etiology

Dry bubble disease caused by *Lecanicillium fungicola* (previously described as *Verticillium fungicola)* is the most devastating diseases in mushroom crops especially in button mushroom (*Agaricus bisporus*) [29; 30;31]. Crop losses can reach 20% or even more if the disease gets out of control, but 1–5% losses are common [32;33].

The primary source of L. fungicola infection in mushrooms is casing material, particularly peat [34] besides that fly vectors (phorid and sciarid flies), workers, watering and contaminated equipment can be major causes of infection [35;31]. Lack of sufficient air circulation, high humidity, late harvesting, and temperatures above 16°C favored pathogen growth, while the maximum fungal growth was observed at 24°C.

Symptoms

After pathogen infection, the distortion symptom takes at least 10 days to appear, while cap spotting is observed after 3-4 days. The optimum temperature for disease development was found to be 20°C [36]. This infection causes a wide range of symptoms, from tiny necrotic lesions to amorphous masses of mushroom tissue[30].

The initial symptoms appeared on the casing layer, then spread throughout the entire surface area, turning grey and yellow [37]. Primary infection drives to some light brown superficial spots appear on the surface of caps which finally coalesce to become large brown patches causing warty outgrowths on mushroom surface [38; 32].

If the infection takes place in the later stages, stipe blow-out (partial distortion or split of stipes) and dry bubble (discolored white undifferentiated spherical mass of amorphous tissue) are formed [29,39].

Control

Management strategies rely mainly on strict hygiene practices, use of fungicide, efficient cultural practices and the application of biological control [5; 29;32;40]. After spawning, a spray of Dichlorvos @30 ml/100 lit. water/100 m3 area can help to prevent the infection and proper care should be taken while preparing and storing casing material to ensure hygiene [5]. According to [41], oil extracts of cinnamon, clove and thyme also can be used as the best alternative in the control of dry bubble disease. Narendra et al. [10] founds that Carbendazim, Thiophanate-methyl, Dithane Z-78 and

Dithane M-45 are effective in inhibition of pathogen. However, some botanicals like *Allium sativum, Matricaria sp., Phytolac sp., Datura stramonium, Morus alba* and *Conium maculatum* also found to be effective with an inhibition percentage of 100% [9].

Wet Bubble

Etiology

Wet bubble, caused by *Mycogyne perniciosa*, is one of the major fungal diseases of button mushroom still affecting the other types too. A diverse range of wild succulent fungus have been speculated to be infected with this mycopathogen [42]. It has a long history on affecting mushroom which dates back to 1888 [43]. Wet bubble disease is predominantly observedin temperate zones, although there's some indication that the infection has been encountered in warmer domains as well [44]. Handlers can potentially spread infections or pathogens by touching them. During ambient day settings, the pathogen con tinued to exist in the state of propagules in the post-mushroom growing medium for up to three years. Water is a secondary route of transmission for the microbe and flies can circulate infections to other mycelia [45;46].

Symptoms

The disease-causing fungus usually sticks to the mushroom and penetrates it at any stage with distinct symptoms of either primordia being converted in shapeless lumps or the color of fruiting body being changed to brown [47]. Wet bubbles enclose the mushroom tumors, which are accompanied by translucent pillowy soft mycelium. Furthermore, amber-colored droplets can be detected [48].

Control

Wet bubble disease is less common when soil that will be used for casing is spawned approximately 5-20 days before pasteurization [49]. Another study revealed that the pathogen's thermal death point was inferred to be 54.4 degrees Celsius for 15 minutes [50]. Whenever the moisture content of casing soil is less than 60% at the time of pasteurization, the pathogen has a longer life expectancy; but it would be unable to thrive in casing soil containing moisture contents of 60% or above at temperatures of 60°C or greater [49]. There has been an intriguing finding that *Acremonium strictum* contains a thermally steady antibiotic molecule, presumably a cephalosporin, that is pathogen suppressive, but so far, no steps have been taken to confirm the findings because both fungi are detrimental to mushrooms [51]. Both in the laboratory and in the mushroom house, two bacterial isolates, B-9 (Bacillus) and B-18 (Alcaligenes), asserted to be excellent bio control agents for the control of wet bubble disease [49]. Among all the fungicides or chemicals scrutinized, carbendazim demonstrated to be the most efficient in combating wet bubble disease when mixed with the casing material [52].

Brown Plaster

Etiology

This disease is caused by the pathogen *Papulaspora byssina.* This disease has been reported from India which leads to decrease in yield of mushroom (*Agaricus bisporus*) by 90% [53] and also has been found to cause complete crop failure in Oyster mushroom [54]. Now, this fungus is usually found at all farms of mushroom of during spawn run. Primary infection through air-borne bulbils or containers, casing soil and compost and workers. The occurrence of brown plaster mould is due to use of poor and old straw, high moisture content in compost, less gypsum or poor-quality gypsum. With reduced grain and straw yield from repeated occurrences of water stress during grain's reproductive phase [55], farmers tend to use a poor and old straw, which fosters the occurrence of the brown plaster mold.

Symptoms

Initially, white and plaster like patches of 6-15 inches in diameter are found over the surface of beds which later turn into tan and then finally to cinnamon-brown colour. The spots of the brown plaster mold mycelium appear much like fine sand. Several brown patches seem to unite to form a continuous coating over the surface of the compost. The fungus reappears when the casing soil is applied lately to infested beds over the surface of the casing soil. Due to this, Mushroom mycelium experience considerable difficulty in penetrating these spots. Thus, the production of sporophores within infected areas is retarded which automatically is related to reduction of yield.

Control

Maintaining proper hygienic conditions helps in controlling of microbial pathogens [47; 29; 56]. Localized treatment of infected patches with 2% formalin is beneficial [53]. Whereas, it is also recommended 4% formalin for the control [57]. Fungicides such as benomyl, carbendazim, thiophanate, vitavax, MBC, methyl, daconil, dithane Z- 78, captan, thiram, dithane M-45, and copper fungicides have reported to work under in vivo and in vitro conditions [58;59]. Various plants extracts are applicable as a control measure [60;61]. *Bacillus velezensis* QST 713, the biocontrol agent is also used

for its control [62]. *Bacillus licheniformis, B. subtilis, B. pimilus and B. amyloliquefaciens* are some of the bacillus strains that inhibit the growth and development of molds in vitro [33;63;64;65]. Some essential oils deter the germination of pathogen on mushroom beds [66].

Cobweb Disease

Etiology

Cobweb disease, caused by the mycopathogenic fungus Cladobotryum mycophilum , is found in all mushroom-growing countries worldwide [67]. Dating back from ancient times mushroom cultivation is a good source of income for many farmers but during the 1990's serious cobweb epidemics started to occur. It was first seen in Europe then later in Australia and USA[6]. Cobweb is a fungal disease that are most commercially seen in white buttom mushrooms. The several members of ascomycete genus as Cladobotryum sp. are the causal agents for development of cobweb disease. Cob web disease affecting mushroom are caused by numerous species of Cladobotryum including C. dendroides, C. mycophilum, C. varium, C. multiseptatum, and C. verticillatum [68]. They produce verticillately or irregularly branched conidiophores [69] bearing two-, three- and four-celled conidia [70]. Infestation of mushroom by cobweb can cause serious production losses upto 40% and reduces the crop surface available. This parasite produced conidia which when released and distributed to the surrounding serves as a secondary point of infection. This disease is reported to appear more often at the end of the crop cycle during the autumn and winter and hence is recurrent in nature [56].

With a closer examination of the disease causing organism was found that the organisms grows well in wetter casings made from freshly harvested deep-dug peats, that provides an ideal moist environment for cobweb spores to germinate [71].

Symptoms

Major symptoms include cottony fluffy greyish white colonies on mushroom casing, rapid colonization of its surface, covering of host by mycelia and their decay, and change of mycelium color to yellowish or reddish/pink in time [72]. At the beginning white small circular patches or basidiomyces appears on the lower casing of soil. Then they spread quickly through a fine grey-white mycelium resembling a spider web [56]. Eventually these patches of mycelium produces a masses of dry spores through sporulation which gets released when they are physically disturbed during watering or picking operations. Air-conditioning systems also facilitates to mobilize the harmful spores. When the spores are released the patches of conidia spreads throughout the mushrooms through air and forms secondary colonies on casing layer[71].[73] Finally the cobweb appears as silky white mycelium with mealy texture over the mushroom and covers it . The mushroom in final stage rots and smells unpleasant[74]. Later when they age, the colonies mushroom changes to pink-red hues.

Control

Prevention is crucial measure to adopt before the emergence of cobweb disease. Good and proper hygiene is required during the production period of mushroom cultivation[71]. The crucial time for removal of any residual disease is end of crop cycle. Wet conidia of Cladobotryum spp. can be killed by treating them at 45 ºC for 30 min, but they can resist up to 100ºC when they are dry. Similarly, pathogenic mycelium, which is treated for 15 min, 40 ºC treatment when wet and 70 ºC for 15 min when dry [75]. The control of cobweb disease is still highly dependent on routine application of fungicides from several chemical groups as prochloraz-Mn (DMI-fungicide, FRAC code: 3) recommended by the European Union [56], Chlorothalonil (chloronitrile, FRAC code: M5) in France, Poland and Spain , Prochloraz-Mn in Australian mushroom crops [73]. Botanical treatment like *Dhatura strymonium, Tagetus erecta, Cannabis sativa, Gadenia spp. , Thooja campacta, Ricinus cumminis,Eucalptus spp*., etc in both dry, hot water and alcoholic extract can be used to treat cobweb disease of mushroom [74].

CONCLUSION AND RECOMMENDATIONS

This review is to redefine the fact that fungal diseases are the rivals of mushroom cultivators by broadly studying the disease etiology, symptoms and their possible ways of control. Rapid identification of disease would be the foremost step for the mushroom growers so that management options could be carried out accordingly to eliminate the probable levels of losses. Applying the appropriate management practices would then be the next step. In general, fungicidal chemicals like Thiabendazole, Carbendazim, and Dithane M-45 are commonly used to control the pathogenic fungi. In specific cases, bio-control agents and botanical extracts are applicable. However, many studies show that chemicals are fast to react against the fungal pathogens as compared to other remedies. Research activities are still to be conducted in this area which will allow us to explore more reliable options for the control of mushroom diseases. Knowledge gained from researches needs to be disseminated from higher levels to the grass-root levels by which even the layman growers will be able to cure the problems in cultivation of mushroom.

Conflict of Interest

The authors declare no conflict of interest.

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