The Pharma Innovation Journal 2021; SP-10(12): 702-712

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; SP-10(12): 702-712

www.thepharmajournal.com
Received: 13-10-2021
Accepted: 15-11-2021

Bhaswati Chakraborty
Department of Plant Pathology, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Archana TS
Department of Plant Pathology, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Corresponding Author
Archana TS
Department of Plant Pathology, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Diseases of mushrooms: A threat to the mushroom cultivation in India

Bhaswati Chakraborty and Archana TS

Abstract
Since prehistory, humans have been aware of mushrooms. Mushrooms are farmed all over the world for their nutritional and therapeutic properties. For a long time, diseases in mushrooms have been a major hurdle in the expansion of the mushroom industry. Several diseases such as Dry bubble, Wet bubble, Cobweb, Bacterial blotch, Internal stipe necrosis and many other contaminants, like the green mold caused by *Trichoderma* spp., Inky caps, False truffle are found to infect mushroom crops at different stages of development. The diseases primarily affect the fruiting body of the mushroom, resulting in reduced quality and yield loss. Each of the diseases is peculiar concerning their symptoms, disease cycle, and epidemiology. The main source of the diseases is the unsterile or poorly sterile substrate. To eliminate pre-existing contaminants, several sterilization techniques such as steam sterilization, hot water sterilization can be used. Furthermore, biological control using botanicals and live antagonists can be used as a prophylactic disinfectant or as therapeutic sprays. Biological control methods are both environment and human health friendly. Biological control measures, unlike chemical fungicides, do not inhibit the mycelial growth of mushrooms and do not raise the issue of pesticide resistance in pathogens. Rouging out of diseased mushrooms as well as sanitizing mushroom houses and managing vector population, are all important in preventing the spread of diseases in mushroom farm.

Keywords: mushrooms, diseases, contaminations, management

Introduction
Man has known mushrooms since antiquity. Mushrooms are macro-fungi that produces fruiting body as their distinctive character. The majority of mushroom belongs to the phylum Basidiomycota and some to phylum Ascomycota like *Morchella*. Fungi constitute a total of 1,10,000 species out of which 16,000 are species of mushrooms. Among 16,000 mushroom species, only 3,000 species are edible [9]. The inedibility of other mushrooms is due to the poisonous properties which are death-dealing. Mushrooms cannot use sunlight for the synthesis of food as they are achlorophyllous. Thus, mushrooms are heterotrophic. Their body is known as mycelium which is formed by the aggregation of thread like structures called hyphae. The hyphae are used for absorption of food and penetration into the medium up to some extent. The life cycle of mushrooms has 2 phases. viz., vegetative phase and reproductive phase. A large number of sexual spores are produced in the later phase. The life cycle is repeated each time the spores germinate to form the mycelium [58, 10, 27, 19].
The edible mushrooms that are mostly cultivated are White button mushroom (*Agaricus bisporus*), Shiitake mushroom (*Lentinus edodes*), Oyster mushroom (*Pleurotus ostreatus*), Straw mushroom (*Volvariella volvacea*), Morel mushroom (*Morchella*) [1].
Mushroom farming has extended its reach to more than 100 countries in recent years. In mushroom production, China has proven to be the largest producer of mushrooms with a production of more than 7.5 million tonnes followed by USA and Netherland. India ranks 10th among the top ten countries in mushroom production. The production and productivity of mushrooms in India have significantly increased in the last few years [19]. White button mushroom, Straw mushroom, and Oyster mushrooms occupy a major share in mushroom production in India. Punjab (14%), Odisha (12%), Haryana (12%) and Maharashtra (9%) are the leading states in mushroom production [11, 48].

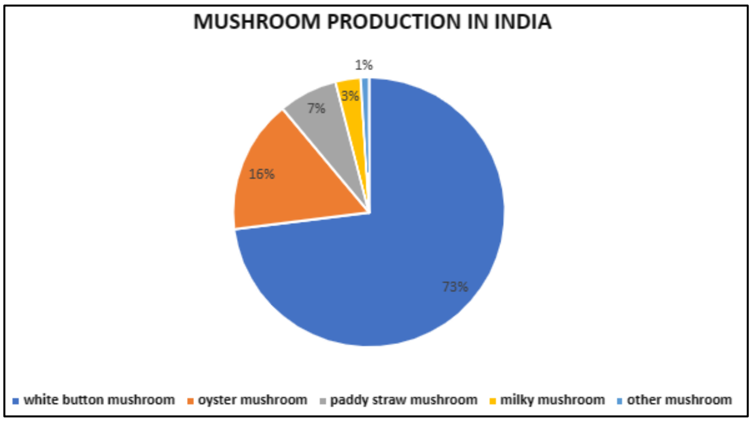

Fig 1: Shares of different mushrooms in total mushroom production in India [19].

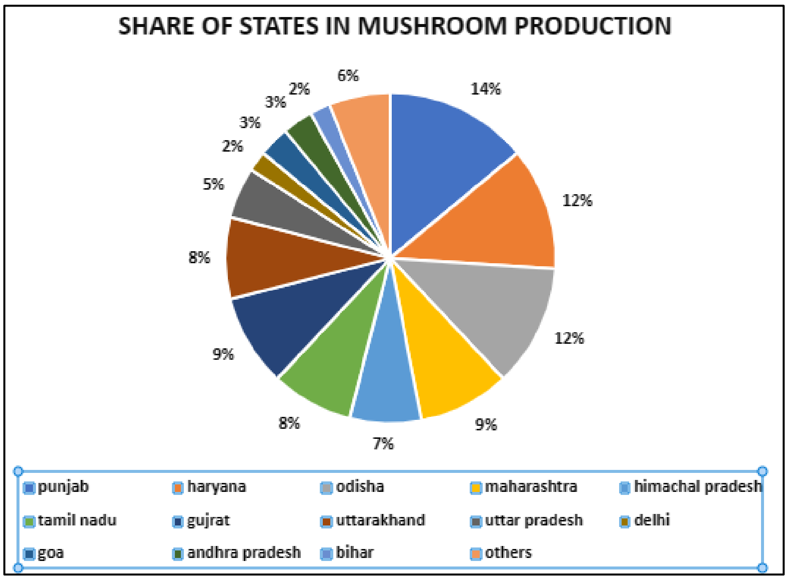

Fig 2: Share of different state in total mushroom production in India [19].

Studies have shown that mushrooms were part of the human diet since ancient times when humans were good hunters. But now, mushrooms have extended their reach not only as a food but also as pharmaceuticals and nutraceuticals. Currently, mushrooms have turned out to be well known because one has high quality meal. The nearby requirement of mushrooms is progressively rising [4].

The demand for mushrooms has increased looking into their valuable nutritional properties. They have become an important and reliable food source because of their dietary values. The nutrient content varies within the species. Along with a high percentage of water (93-95%), mushrooms are also rich in valuable minerals like calcium, potassium, iron and vitamins like vitamin A and Vitamin B. They also contain carbohydrates, fats, proteins and ash [49] (Table 1). They are low in calories and high in protein, so are recommended for heart patients. Due to the low content of starch in mushrooms, it becomes a supreme food for diabetic patients. They are also rich in essential amino acids which are crucial for human growth and development. Mushrooms are considered a suitable replacement of muscle protein due to their high digestibility. They are also considered as an outstanding source of Vitamin D which is generally lacking in other food supplements [23, 22, 39].

Many scientists have reported that mushrooms are a good source of vitamins like Vitamin B_1 (Thiamine), Vitamin B_2 (Riboflavin), Vitamin B_3 (Niacin), Vitamin B_{12} (Cobalamine), Vitamin C (Ascorbic acid), Vitamin D (Calciferol) and Vitamin H (Biotin). Generally, Vitamin B_{12} deficiency is associated with vegetarian diets as it is of animal origin but the inclusion of mushrooms in the diet will fulfill the body's requirement of cobalamine. The nutritive value of most of the edible mushrooms are comparable to that of meat and milk. But not all mushrooms are nutrient rich. *Pleurotus ostreatus*, has low protein content due to deficiency of some essential amino acid so, it has a low nutritive value. Overall, mushrooms can be considered as a superfood with valuable constituents for daily diet [34].

Table 1: Nutritional parameters of mushrooms [14, 2].

Parameters	*Agaricus bisporus*	*Pleurotus spp*	*Volvariella volvacea*	*Lentinula edodes*
Carbohydrates (%)	51.05	64.34	38.10	18.85
Protein (%)	29.14	19.59	38.10	18.85
Fats (%)	1.56	1.05	0.97	1.22
Ash (%)	9.7	5.7	10	6.7
Vitamin D (IU/g)	984	487	462.04	205

Also, mushrooms are valued for its medicinal provision which is exploited by humankind for a long time now. Medicinal mushrooms have an established history when we look into the past. Ganoderma and Lentinula are the two most vital species when we consider medicinal mushroom. Mushrooms are reputed to possess anti-tumor, anti-cancer, anti-viral, anti-bacterial, cardiovascular, anti-diabetic, antioxidant and anti-inflammatory properties [28, 59, 60, 49, 34].

Polysaccharides present in mushrooms are known to prevent oncogenesis and have direct tumor suppressing effects. Presence of certain bioactive agents like lectins (white button mushroom), lovastatin (oyster mushroom), lentinan (shiitake mushroom), ganoderic acid beta-glucan (reishi mushroom), ergothioneine (winter mushroom) and acid polysaccharides (wood ear mushroom) are found to improve the immune functions of human body due to their immunomodulating properties. The antioxidant properties of mushrooms are due to the presence of several bioactive compounds. These are known to prevent oxidative damage to the body. The antioxidants are confined to be phenolics, flavonoids, glycosides, polysaccharides, tocopherols, ergothioneine, carotenoids and ascorbic acid [62, 5, 38, 48].

It is a heartful desire of a farmer to get a disease-free harvest. However, fungi, bacteria, viruses and nematodes have been known to cause major diseases and are becoming a daunting task to manage them. The source of infection mainly comes from unsterilized substrate and casing material. Diseases reduce the quality of mushrooms and ultimately leads to reduced production and sometimes to a total crop failure. The production of fruiting body is severely affected when attacked by disease causing microorganisms. The major diseases in mushroom can be classified as fungal, bacterial and viral. It's strange to notice that mushrooms itself being a fungus is attacked by other fungi. The diseases are peculiar in terms of symptomatology, disease cycle, epidemiology [1, 40, 3].

Fungal Diseases

The most common fungal diseases that are noticed are Dry bubble (*Lecanicillium spp.*), Wet bubble (*Mycogone perniciosa*), Cob web (*Cladobotryum spp.*).

1. Dry bubble disease

Lecanicillium fungicola (syn. *Verticillium fungicola*) is the causal organism of dry bubble disease of cultivated mushroom. It infects various species of mushroom like the oyster mushroom but is one of the most common and serious disease in white button mushroom (*Agaricus bisporus*). The fungus belongs to Ascomycota producing hyaline, oblong to cylindrical single celled conidia laterally or terminally on the vertically erect conidiophores. Under laboratory conditions, the colonies formed by the pathogen are rounded with regular edges and are radiating [29, 41].

Depending upon the time of infection there are number of different symptoms noticed. Disease symptoms include bubbles, bent, split stipes known as blowout and spotty caps. When the contamination is at a totally early age, small round mass of tissue like appearance are seen at the mushroom pins. Infection during early maturation stage causes split stripes and partial deformation in the infected mushroom. On older developing mushrooms wart-like appearance occurs on the mushroom cap. If the mushrooms are affected at the matured stage, the stipe and pileus are imperfectly formed. The stalk arches, the cap inclines causing stripe blow-out. Grey-brown spots (necrotic lesions) are developed on the mushroom caps of fully formed mushroom which are infected. The browning which is associated with *Lecanicillium fungicola* is due to the formation of melanin in the infected area [3, 41, 14, 6].

Fig 3: Fruiting body of *Agaricus bisporus* infected by *Lecanicillium fungicola* displaying different symptoms: (A) healthy mushroom; (B) necrotic lesions; (C) stripe blow-out; (D) dry bubble [6].

Gea and Maria, 2017 [14] reported that the primary source of dry bubble disease is the casing material especially peat. But research conducted by Nair *et al*., 1987 [35] showed that large number of the pathogen was extracted from soil than from peat. Hence, the primary source of inoculum of dry bubble disease is still under debate. The dry bubble spreads easily in the mushroom farm. This is because the mass of conidia produced by the fungus is covered by sticky mucilage which easily comes in contact with insects, dust, tools and clothes. After the infection, an incubation period of 12 to 14 days is required before the manifestation of the symptom. Once the disease is established on the farm, there is a continuous supply of the sticky conidia which makes the dissemination very quick. The first infection occurs when the casing material gets contaminated either by windblown dust or by insects or humans. If during the first infection the disease remains undetected and untreated, it starts to spread to adjacent mushrooms by water splashes during watering of the mushroom crop or by insect like flies. Sciarid and phorid flies are known to transmit about 84-100% and 76-100% of *Lecanicillium fungicola* respectively under laboratory conditions [25].

If the diseased is not managed timely, it can cause crop loss as high as 20% or more. The most effective way to manage the disease is to follow strict hygiene practices which will prevent the introduction of inoculum in the mushroom farms. Controlling the population of insects such as mites and flies can prevent the spread of the disease throughout the farm. Application of fungicide such as dichlorvos @30 ml/ 100 lit water / 100 m3 area after spawning can restrict the growth of the pathogen. Although the most effective chemical for inhibition of the pathogen is Prochloraz followed by Chlorothalonil. Other management measures include the removal of the diseased mushroom before watering, thorough cleaning and disinfestation of the entire farm once a crop cycle is complete. Also, the casing material should be kept in a place where it will not get contaminated easily. A poor understanding of how the disease spreads within and between mushroom crops has been a contributing factor in persistence of dry bubble problem [17, 55, 6, 24, 14, 3].

2. Wet bubble disease

Wet bubble disease is caused by *Mycogone perniciosa.* It is a mycoparasitic ascomycota fungi affecting commercial cultivation of different mushrooms (*Agaricus bispsorus*, *Pleurotus ostreatus*, *Volvariella volvacea* etc.) in major growing countries. The disease mainly spreads through pieces of mycelium and the spores of the fungi. *Mycogone perniciosa* produces two types of spores namely conidiospores and chlamydospores. Conidiospores (conidia) are unicellular and thin-walled with a short live span whereas, chlamydospores are bi-celled, thick-walled and have longer live span. Both the spores are known to spread easily through irrigation practices. Studies have found *Mycogone perniciosa* affect only the fruiting body and the vegetative part of the mycelium remains unaffected [15, 12, 1].

The disease is characterized by the formation of white mycelium growth on the fruiting body of the mushroom and the presence of deformed mass of tissue called the "sclerodamoid mass" which is mainly a result of early infection at pin head stage. Bubbles are formed on the fruiting body which initially appear to be white, feathery and spongy but later they become brown and decay. Exudation of extracellular fluid formed at the infected area results in a phenomenon called the tear-drop (hence, named as wet bubble). The reported unpleasant smell after rotting is due to the presence of bacteria and spores in the amber liquid droplets formed at the infected area [57, 3, 33, 53].

Fig 4: Deformed mass of tissues (sclerodamoid mass) formed on the fruiting body of *Agaricus bisporus* due to infection by *Mycogone perniciosa*

Fig 5: Wet bubble disease by *Mycogone perniciosa* leading to browning and decaying of the fruiting body of *Agaricus bisporus.*

Fig 6; Amber colour liquid drops can be seen on the surface of the diseased mushrooms infected by *Mycogone perniciosa* [14].

The casing material is considered as the main source of infection of wet bubble disease. The pathogen is known to spread through water splashes and also through aerial transfer of the conidia. The pathogen in the farm also spreads through contaminated tools, clothes etc. Sharma and Kumar, 2000 [46] reported that wet bubble disease in *Agaricus bisporus* can cause yield loss as high as 80% in artificially inoculated medium. In severe conditions, it can cause a 100% yield loss during natural incidence of the disease. Hence, wet bubble is found to have a devastating nature in *Agaricus bisporus* farms with a high yield loss under favorable conditions and even a total crop failure under severe conditions [53, 63].

Timely management of the disease becomes important as it can cause a heavy loss. Following strict hygiene practices along with using sterilized casing material is of utmost priority to manage and to prevent this disease. Munshi *et al*., 2010 [33] reported that the spray of benomyl @ 0.5g/m^2 immediately after casing is found to be effective in protecting the crop. Also, the spray of formalin 0.8% on the casing material is found to be effective against wet bubble disease. Other management practices include controlling of insect population in the farm, cleaning of the farm after each cycle of the crop and using non-contaminated tools while working in the farm [3, 19, 14].

3. Cob web disease

The causal organism of cob web disease is *Cladobotrym dendroides* (syn *Dactylium dendroides*). This disease is also known as the soft mildew of mushroom. The pathogen belongs to the phylum Ascomycota and its presence is characterized by an irregular apex phialides and large conidia. The mycelium is initially white in color but later changes into reddish tone while aging. In addition to that, a characteristic camphor smell is produced by the colonies of the pathogen [14].

Mushrooms are attacked at any stage of their development. The disease's signature symptom is the growth of white cob-like mycelium patches that grow over the casing material and engulf mushrooms along their path. The mycelium shows a rapid colonization quickly trapping the stripe and the fruiting body of the mushroom. The severely affected mushroom turns brown or black and rots. Gradually the mycelium changes its color to pinkish or reddish and the cob-web appearance is replaced by the mycelium mat. Another noticeable symptom of the cob web is the formation of cap spotting on the fruiting body. The spots are light to dark brown with poorly defined border [1, 33, 14].

Fig 7: Cobweb mycelium on the surface of the casing and attacking mushrooms.

Fig 8: Cobweb mycelium causing cap spotting [14].

The pathogen being a soil inhabiting fungus, it is considered that the conidia or the mycelium from the soil is the major source of contamination. The contamination reaches the farm with the casing material that is being used. High relative humidity and temperature are the most favorable conditions for the disease development. After the advancement of the disease dry spores starts to release and infects the nearby mushroom with the help of air current and various other agents. Sciarids and Phorids are the most suitable vector for the spread of the disease in the farm. Hence after the outbreak of the disease in the farm, it becomes very difficult to control because of the level of mobility it gets due to the dry airborne spores [47, 18].

Comprehensive identification of Cob web disease is important before irrigating the farm. Watering over the untreated infected area can carry a massive spore load throughout the farm. Proper ventilation and prevention of excess humidity is very important to reduce the growth as well as spread of the pathogen. Sterilizing the casing material at 50-degree Celsius for 4 hours is important. Also, after each crop routine the entire room should be steam sterilized to control of the disease. Use of benomyl @ 1 g in 0.5-1.0 L water/m2 or prochloraz manganese complex (Sporogon) 1.5 g a.i/m2 of bed 9 days after casing [33, 18].

During mushroom cultivation, many harmful fungi are found in compost and casing materials. Some of them act as competitor moulds, while others attack fruiting bodies at different stages of development. These moulds frequently cause crop failure, depending on the stage and severity of infection, the quality of compost, and the prevailing environmental conditions. Some of the most important parasitic moulds and weed fungi, as well as the abnormalities they cause, are listed below.

a. Green mould

Trichoderma spp. are known to causes green mould which is a devastating disease in mushroom crop production. In India, it has been documented to cause significant crop damage. The *Trichoderma* spp. have wreaked havoc on mushroom farms of Kashmir Valley. Trichoderma spp. are very dominating against all fungi and have a high outbreak potential [45, 7].

On spawned and cased bags, this mould infection appears as a thick cushioned white area with greenish fungal growth that progressively changes to blue green colour. In its early stages, *Trichoderma* spp. develops a dense pure white mycelium that looks similar to the mushroom mycelium, making it difficult to differentiate the two. The spawn-run will be harmed if this fungus infects the spawned trays. The pin-head production of mushrooms is impeded if it develops on casing soil. The green mould fungus colonises organic matter and dead mushroom tissue rapidly. Inadequate phase-II composting and high humidity are additional factors in the disease spread. The fungal spores are dispersed by air, water, and reckless handling. Use of Carbendazim is found effective against this disease. Certain bacteria, such as *Bacillus* species which are found naturally in casing, are effective antagonists of aggressive *Trichoderma* strains, suggesting that they could be exploited to treat green mould diseases [3, 45, 19].

b. Yellow mould

Yellow mould is caused by *Sepedonium chrysoporium*. Yellow mould disease is distinguished by white mycelium that gradually turns yellow to tan in appearance. Initial indications of yellow mould disease include yellow brown corky mycelium on the interphase of compost and casing, which emits a strong metallic odour comparable to carbide [56].

The contamination has been found to cause a 5-20% yield decrease in button mushroom production. Spores generated on the surface of yellow mould spread to compost with the help of wind flies, human activity, and other factors. At 70 percent moisture and a compost temperature of 19-200°C, this disease is highly severe [47].

c. Pink mould

Cephalothecum roseum is the causal organism of pink mould. This is one of the fungal contaminants that compete with mushroom in the farm. It appears as white growth on the casing soil during the early stages of contamination and then turns pink. According to Sharma *et al*. 2007 [47], this fungus has been responsible for up to 90% yield loss or complete crop failure. It reproduces asexually through the formation of conidia with no discernible sexual stage [50].

The ideal conditions for fungus growth and development are 25 °C and pH 6.0. Rapid sporulation is aided by the combination of a low temperature (15 °C) and a pH range of 4.0-6.5. Higher glucose concentrations can increase the size of conidia, which are found floating in the air and moving from one place to another, making air the primary route of fungal infection during mushroom cultivation [47].

d. Inky caps

Coprinus spp. is also one of the most common fungal contaminants in *Pleurotus* spp. mushroom beds. *Coprinus comatus*, a member of the Agaricales family, is a common fungus found all over the world in lawns, waste areas, and along gravel roads. *Coprinus* spp. can be found in composts or substrates during spawn run or casing beds, as well as outside manure heaps during the fermentation process. The Coprinus spp. is characterized by the appearance of a ring on the stem, pinkish young gills, and a string-like strand of fibres in the hollow stem. They are usually covered with scales and appear cream-colored at first, then bluish black later [26, 30, 21, 8, 47].

Ammonia, which is present in compost during peak heating, promotes Coprinus spp. infection in oyster mushrooms. The appearance of black inky liquid confirms the presence of ammonia in the compost. Depending on the climatic conditions, the incidence of fungal contaminants is lowest in January (2.87 percent) and highest in June (32.8 percent) [30].

e. False truffle disease

Diehliomyces microsporus is known to cause false truffle disease of mushroom. The pathogen belongs to Ascomycota and produces reddish brown ascocarps. The ascocarps aggregate to form large groups on the surface of the casing material. *Diehliomyces microsporus* spores mature 3–6 weeks after the fruiting bodies form. When the spores are released, the ascocarps disintegrate into a brown powdery mass. The germination of the spores is stimulated mainly by the presence of actively growing mushroom mycelium, as a result, the fungi's growth rate increases as the mushroom mycelium's growth rate increases [14].

The emergence of a dense yellowish white mycelium in the compost pile at the bottom is the first sign of the presence of false truffle. the pathogenic mycelium is thicker and greyish white than mushroom mycelium, although it is first difficult to distinguish between the two. On other occasions, it has been observed covering the casing material as a cottony white mycelium growth in some portions of the packed substrate prior to the emergence of this yellowish mycelium in the mass of compost. The mycelium develops into fruiting bodies that resemble peeled greyish white walnuts. Fruiting bodies can coalesce into huge masses that occupy the majority of the substrate package, and they can be found in both compost and casing material [14].

The main source of contamination comes from the soil. The presence of false truffle prevents the growth of mushroom mycelium on the compost, which can cause the compost to become saturated and dark, resulting in a sharp drop in production. Mushrooms growing on the outside of the affected area become yellow and perish before they reach an adequate size. When the crop is harmed before or during incubation, significant harvest losses can occur, with yield reductions of up to 75% [14].

Table 2: Disease, causal organism and management of major fungal diseases of cultivated mushroom.

Sl No.	Diseases	Causal Organism	Management	Reference
1.	Dry bubble	*Lecanicillium fungicola* (Syn. *Verticillium fungicola*)	Heat treatment of infected casing material at 63 degrees Celsius for 1 hour. Use Dithane Z-78 @0.25-0.5% at the time of casing, pin head formation and after crop flushes. Use of *Bacillus* sp. as biocontrol agent (shows antagonistic activity).	[33, 52].
2.	Wet bubble	*Mycogone perniciosa*	Remove diseased mushrooms and sterilize beds with 2% formalin. Benomyl @ 0.5g/m^2 application immediately after casing.	[33, 12].
3.	Cob web	*Cladobotrym dendroides*	Apply Benomyl @ 1 g in 0.5–1.0 L water/m2 or Prochlorag manganese complex (sporogon) 1.5 g a.i/m2 of bed 9 days after casing.	[33].
4.	Inky caps	*Coprinus* sp.	Use properly pasteurized compost and casing material. Avoid excessive watering.	[33].
5.	False truffle	*Pseudsbodasamiamicrospora* or *Dichdiomyces microspora*	Avoid high temperature (26–27°C) during spawn-run and after casing. Remove affected truffles and apply formaldehyde @ 2% solution on the affected patches.	[33].
6.	Green mould	*Trichoderma* sp.	Spray Dithane M-45 @ 0.2% or carbendazim 0.05%. Use of bacillus sp. as biocontrol agent.	[33, 52].

Bacterial Diseases

1. Bacterial blotch or brown blotch

Bacterial blotch was reported by Tolaas in 1915 in USA but the etiology was later explained by Piane. *Pseudomonas tolaasii* is considered as the causal organism of bacterial blotch of white button mushroom. The same pathogen is known to cause the yellowing of *Pleurotus ostreatus*. Although the species *tolaasii* is considered to be the main causal agent but various other species of Pseudomonas as well as organisms from other genera have been reported to cause blotch symptoms on the fruiting body of mushroom. Among all the biotic constraints of cultivated mushroom, bacterial blotch is considered as one of the most serious disease of the cultivated mushroom in terms of global and economic impact. The disease can vary from small lesions occurring on few mushrooms to engulfing the entire mushroom bed in severe conditions [37, 54, 16, 31].

The symptom of the disease is characterized by concave brown-stained lesions of circular or irregular shaped on the mushroom cap. The browning is restricted to only few millimeters below the cap surface. Hence, the browning affects mainly the external area of the cap region of the mushroom. The affected underlying tissue is found to develop water-soaked lesions which are grey in color. During favorable environmental conditions, small lesions are formed which are separate but with the development of the disease the lesions coalesce and affects major area of the pileus. The bacteria show rapid multiplication when the surface of the fruiting body remains wet and the infected mushrooms becomes sticky in touch. Both the stalk and the cap may get affected by the pathogen. When the exudates from the mushroom cap stimulates the bacteria, it produces tolaasin as the end product of the metabolism. At suitable concentration this substance can be toxic to the mycelium and can cause lysis of the cap tissues. It is also considered as a post-harvest disease because sometimes the fruiting body seems healthy but after the harvesting, they develop the disease during the storage and causes post-harvest losses. The blotching symptom of *Pseudomonas tolaasii* is easily confused with the browning symptoms of other disease-causing pathogen in mushroom like *Lecanicillium, Cladobotryum* and *Trichoderma*. Therefore, the identification of the disease becomes quite confusing and difficult [51, 37, 44, 13, 14, 16, 36].

Fig 9; Brown-stained lesions on the cap of the mushroom (*Agaricus bisporus*) along with the infected pileus [14].

The bacteria can enter into the farm either through the compost or the casing material but the environmental condition of the farm influences the development of the disease. Environmental conditions play a very important role in the appearance and severity of the disease. High relative humidity and changing temperature induces the development of the disease in the farm. Humidity and temperature are the two most important factors that are to be controlled to minimize the incidence of the disease. Once the disease is established it then starts spreading with hands, tools, watering, pest and so on. Insect vectors like the Phorid flies and mites are known to spread the disease. The disease is also favored by the low temperatures on the inside of the compost [14, 36, 32].

Lowering of humidity to 80 per cent and running fans immediately after watering to dry the caps so as to prevent the bacteria to spread on the growing sporophores. On should try to avoid temperature fluctuations. The temperature should be so controlled that the dew point is not reached. If the temperature is below the dew point, then water vapour will condense on the surface of the fruiting body which will lead to the severe incidence of the disease as the conditions becomes favorable for the pathogen. The management of the disease is only possible when the ventilation and temperature conditions are managed to a level where the pathogen cannot sustain its growth and development of symptoms. For chemical control, spray the beds with 100 ppm bleaching powder [19, 3, 54].

2. Internal stipe necrosis

Internal stipe necrosis is caused by *Ewingella americana*. The pathogen is a member of Enterobacteriaceae. This disease is seen as an emerging and potential disease in the mushroom industry. The bacterium has been found associated with human host also. The symptom of the disease is visible only upon harvesting. Various strains of Pseudomonas fluorescens are also present in the diseased mushroom. The hypothesis that the disease is of bacterial origin comes under doubt. So, the affected or symptomatic mushrooms were examined extensively and it was found that the bacterium E. americana was isolated from at least 93% of the symptomatic mushrooms whereas P. Fluorescens was not consistently associated with the disease. Moreover, the strains recovered from the diseased mushroom were used for infection trials. The results of the trial confirmed the Koch's postulates for the strain [20].

Internal stipe necrosis signs include a varied browning reaction in the center of the mushroom stipe, as well as a mild browning of internal cap tissue abutting the stipe core in certain specimens. Affected tissues may collapse as the mushrooms grow, leaving just a brown peg of dry tissue sticking to the inside of the cap in some cases. The brown tissue that is formed in the stripe becomes dry and collapse leaving a hollow center. There is no evidence of symptoms progressing beyond this point, implying that the condition is self-limiting. Damage is only revealed after harvest in all circumstances [14].

Fig 10: Agaricus bisporus infected with *Ewingella americana* causing internal stipe necrosis [14].

Fig 11; Hollow center symptom of internal stipe necrosis of white button mushroom [14].

Internal stipe necrosis has been linked to waterlogging of mushroom stalks at an early point in their growth, hence good evaporation from the bed surface should be maintained at all times. After the primordia of the first flush have appeared, an excessively low compost temperature may favour the spread of E. americana. After casing, the key period is during incubation and fruiting induction. As a result, maintaining evaporation from the casing and avoiding waterlogging of the casing material is recommended to reduce the incidence of the disease. To control the bacterial population, chlorine (155 ppm) can also be used [14, 20].

3. Drippy gill disease

The disease is caused by *Pseudomonas agarici* n.sp. The gill tissue of the cultivated mushrooms is specifically damaged by the bacteria. The *agarici* species is distinct from other species that cause disease in mushrooms. The reverse transformation of *P. tolaasii* and *P. gingeri* from pathogenic to saprophytic is most common, but *P. agarici* does not readily undergo this transformation A profuse bacterial ooze issuing in droplets from hymenial lamellae and longitudinal breaking of the stipe with an associated bacterial ooze describe 'Drippy gill' disease. People have assumed that the causal organism is transmitted intra hyphally due to the nature of the symptom expression [61].

Small dark brown or black, round or elliptical spots appear on the side and bottom edges of the lamellae (gills) of mature mushrooms in the early stages of the disease, which later develops. These areas are darkest in the center and lightest on the outskirts. A cream-grey droplet may appear clearly on the gill surface at the middle of each area. These droplets may increase in size and bridge the gap between the gills. The droplets are occasionally discovered inside immature caps with unbroken veils and little or no browning of the tissue. The droplets are filled with bacteria of a single colony type. If the infection is mild, the mushroom may suffer little damage, but local collapse of the darker gill tissue may occur. If the infection is severe, bacterial droplets aggregate on and between the gills to produce slime ribbons, and the gill tissue gradually collapses. Early infection appears to inhibit cap development in some cases and may be responsible for pileus distortion. A characteristic symptom of severe infection is a lack of color in the affected tissue, which could be caused by the hymenial layer failing to mature. Affected gill tissue is cream-khaki in colour and collapsed, distorted, and gelatinous. Aside from the distortion of the developing cap, the damage to pileus tissue appears to be limited entirely to the gills. Their inner surface is gleaming, and microscopic examination reveals that they are teeming with bacteria. These splits become dark brown as the mushoom matures. The disease is known as "drippy gill" because of the characteristic symptom of bacterial droplets developing on the gills [42].

Viral Diseases

Viruses attack mushrooms, causing diseases such as La France, watery stripe, X-disease, and brown disease, which have the potential to cause significant crop loss. The viral diseases were not previously documented in India, but they were recently reported in Bangalore. Elongation of the stalk with a tiny, slanted crown is the most typical sign (drumstick). Mycelium degradation (die back) is prevalent, and it gets worse over time. Small brown mushrooms appear from time to time, and they often open prematurely. When pressed, affected fruiting bodies exhibit a water-soaked appearance (watery stripe) and are completely water-logged [19, 3].

La France Disease or Die-Back

All the stages of mushroom are considered critical to the die-back. There are several symptoms related to the viral diseases in mushrooms, however they are rarely present at the same time. The disease causes a delay in mushroom fruiting in its most severe form. Host genotype, infection timing, culture conditions, and other unknown factors all determine the severity of La France. Symptoms range from a chronic infection with barely noticeable yield reduction to an acute infection with deformed fruiting bodies and complete crop failure [43]

Deformations in the fruiting bodies, such as elongation of the stipe, tilting of the cap, thickening at the stipe's base, and tiny caps on slender or normal stipes, are the most common signs. This condition is known as "drumstick," and it's easy to confuse it with mushrooms produced in a high-CO_2 environment. These mushrooms are usually only loosely attached to the shell, and their veils open prematurely, allowing spores to escape. In addition, the inside section of the tissue of mushrooms has a few long brown dots. The gills of infected mushrooms are sometimes underdeveloped and turn a bright color. The symptoms of the virus can be mistaken for those of mummy illness in rare cases [14].

Fig 12: Drumstick symptom of mushroom affected by La France [14].

On the casing, the damaged crops take on an uneven appearance with inadequate mycelial growth. The mycelium eventually becomes weak and degenerates, leaving the compost moist. In many cases, the casing shows areas that are completely devoid of mushroom mycelium, which might be exploited by competing fungi to colonize these places. The mushrooms may mature too soon, causing the cap to open prematurely. Some of the crops that are damaged don't display any symptoms, yet they incur losses during harvest. Crop losses are significant when crops are impacted at an early stage [43, 14].

Viruses are transferred from mycelium to mycelium, by merging of hyphae, and through mushroom spores that germinate and convey the virus to healthy mycelium through anastomosis. It's critical to reduce or remove the virus's ability to enter fresh crop cycles at any stage through spores or fragments of contaminated mycelium. Surfaces, machines, and workers' clothing should all be cleaned and disinfected as part of the hygiene programme. Prior to usage, every machinery in the composting industry must be cleansed and disinfected. Casing materials must be kept in a clean environment. When possible, give the crops a thorough steam treatment and before the spores are released, collect the immature carpophores to prevent any further contamination. Varieties can also be alternated to limit the amount of virus inoculum [43, 14].

Conclusion

The inclusion of fresh varieties of mushrooms for commercial cultivation has inflated the global mushroom business in the last two decades. Furthermore, mushroom cultivation and development had a favorable impact on economic growth, and the impact of mushroom farming and mushroom derivatives and products on human welfare in the twenty-first century can be globally referred to as a "non-green revolution".

A farmer's major goal is to produce high-quality harvests, however disease outbreaks on the farm becomes a major constraint. Several fungal, bacterial, and viral infections have been discovered to impair mushroom output and quality, either by competing for food and space or by releasing toxic compounds. The disease entered the farm mostly due to a lack of basic hygiene standards and the use of unsterilized materials for cultivation. The pathogen enters the farm mostly through unsterilized casing material in the majority of fungi-causing diseases. If a disease is recognized and treated early in its development, the severity of the disease on the farm can be minimized. To remove impurities, steam sterilization, chemical sterilization, hot water treatment, bleaching, therapeutic herbal sprays, and biological antagonists can be used. Apart from sanitation, rouging, varietal selection, and vector management, are few other cost-effective ways to avoid infection.

Reference

1. Ghimire A. *et al*. Int. J. Appl. Sci. Biotechnol 2021;9(2):80-93.
2. Ahlawat OP, Manikandan K, Singh M. Proximate composition of different mushroom varieties and effect of UV light exposure on vitamin D content in *Agaricus bisporus* and *Volvariella volvacea*. Mushroom Research 2016;25(1):1-8.
3. Amin, Zakir, Fazil Fayaz Wani, Humaira Gulzar, Dar WA, Sheikh PA. "Diseases of White Button mushroom (*Agaricus bisporus*)-A potential threat to mushroom industry." Int J Curr Microbiol App Sci 2021;10(02):2076-2085.
4. Anam Zahid, Muhammad Ramzan, Fozia1, Safyan Ahmed Nutritional and Medicinal Significance of Paddy Straw Mushroom (*Volvariella volvacea*), 2019.
5. Barros, Lillian, Maria-Joao Ferreira, Bruno Queiros, Isabel CFR Ferreira, Paula Baptista. "Total phenols, ascorbic acid, β-carotene and lycopene in Portuguese wild edible mushrooms and their antioxidant activities." Food chemistry 2007;103(2):413-419.
6. Berendsen, Roeland L, Johan Baars JP, Stefanie Kalkhove IC, Luis Lugones G, Han AB Wösten, Peter AHM Bakker. "*Lecanicillium fungicola*: causal agent of dry bubble disease in white-button mushroom." Molecular plant pathology 2010;11(5):585-595.
7. Bhandari, Sagar, Krishna Raj Pandey, Yagya Raj Joshi, Sudip Kumar Lamichhane. "An overview of multifaceted role of *Trichoderma* spp. for sustainable agriculture." Archives of Agriculture and Environmental Science 2021;6(1):72-79.
8. Biswas MK, Sanjeeb Kuiry. "Yield performance of different species of oyster mushroom (*Pleurotus* spp.) under the agro-ecological condition of lateritic zone of west Bengal, India." International Journal of Bio-resource and stress management 2013;4(1):43-46.
9. Chang ST, Wasser SP. The cultivation and environmental impact of mushrooms. Oxford Research Encyclopedia of Environmental Science 2017. https://doi.org/10.1093/acrefore/9780199389414.013.231
10. Chang ST, Miles PG. "Mushroom biology—a new discipline." Mycologist 1992;6(2):64-65.
11. FAO. Top 10 country production of macrofungi and truffles, 2016. Retrieved from http://www.fao.org/faostat/en/#rankings/countriesbycommodity
12. Fletcher JT, Drakes GD, Talent CJW. The control of wet bubble disease of mushrooms caused by *Mycogone perniciosa*. Annals of Applied Biology 1975;79(1):35-41.
13. Gaze, Richard H. Mushroom Pest and Disease Control: A Colour Handbook. Manson Publishing, 2008.
14. Gea, Francisco J, María J. Navarro. "Mushroom diseases and control." Edible and medicinal mushrooms: technology and applications, 2017, 239-259.
15. Gea, Francisco J, Julio Tello C, María-Jesús Navarro. "Efficacy and effects on yield of different fungicides for control of wet bubble disease of mushroom caused by the mycoparasite *Mycogone perniciosa*." Crop Protection 2010;29(9):1021-1025.
16. Gill WM. x Bacterial diseases of Agaricus mushrooms. Rep. Tootori Mycol. Inst 2010;33:34-55.
17. Grogan H, Piasecka J, Zijlstra C, Baars JJP, Kavanagh K. Detection of *Verticillium fungicola* in samples from mushroom farms using molecular and microbiological methods. Agricultural Research Forum, 2009, 131 (http://www.agresearchforum.com/publicationsarf/2009/proceedings2009.pdf).
18. Grogan, Helen, Richard Gaze. Identification and control of Cobweb disease on mushrooms. Teagasc (Agriculture and Food Development Authority), Ireland, 2008.
19. Gupta, Sachin, Baby Summuna, Moni Gupta, Sudheer K. Annepu. "Edible mushrooms: cultivation, bioactive molecules, and health benefits." Bioactive molecules in food, reference series in Phytochemistry. Springer 2018, 1-33.
20. Inglis, Peter W, John Burden L, John Peberdy F. "Evidence for the association of the enteric bacterium

Ewingella americana with internal stipe necrosis of *Agaricus bisporus*." Microbiology 1996;14(11):3253-3260.

21. Jang, Myoung-Jun, Yun-Hae Lee, Jun-Jie Liu, Young-Cheol Ju. "Optimal conditions for the mycelial growth of *Coprinus comatus* strains." Mycobiology 2009;37(2):103-108.
22. Kalač, Pavel. "Chemical composition and nutritional value of European species of wild growing mushrooms: A review." Food chemistry 2009;113(1):9-16.
23. Koyyalamudi, Sundar Rao, Sang-Chul Jeong, Chi-Hyun Song, Kai Yip Cho, Gerald Pang. "Vitamin D2 formation and bioavailability from *Agaricus bisporus* button mushrooms treated with ultraviolet irradiation." Journal of agricultural and food chemistry 2009;57(8):3351-3355.
24. Kumar N, Mishra AB, Bharadwaj MC. Effect of *Verticillium fungicola* (PREUSS) HASSEBR inoculation in casing soil and conidial spray on white button mushroom *Agaricus bisporous*. African Journal of Agricultural Research 2014:9(14):1141-1143.
25. Kumar Satish, Sharma SR. "Transmission of parasitic and competitor moulds of Button Mushroom (*Agaricus bisporus*) through flies." Mushroom Research 7, 1.
26. Kuo, Michael. "Coprinoid mushrooms: The inky caps." (2008).
27. Hongyun Lu, Hanghang Lou, Jingjin Hu, Zhengjie Liu, Qihe Chen. "Macrofungi: A review of cultivation strategies, bioactivity, and application of mushrooms." Comprehensive Reviews in Food Science and Food Safety 2020;19(5):2333-2356.
28. Mau, Jeng-Leun, Chieh-No Chang, Shih-Jeng Huang, Chin-Chu Chen. "Antioxidant properties of methanolic extracts from *Grifola frondosa*, *Morchella esculenta* and *Termitomyces albuminosus* mycelia." Food chemistry 2004;87(1):111-118.
29. Maurya, Amit Kumar, Rakhi Murmu, Vinny John, Bhagyashree Kesherwani, Mahesh Singh. "Important Diseases and Pests of Mushroom." Agriculture & Food: E-Newsletter 2019;1(12):189-193.
30. Maurya, Amit Kumar, Vinny John, Utkarsh Singh Rathore. "Cultivation Techniques of Oyster Mushroom (*Pleurotus* sp.)." in Food Technology and Nutrition 2020, 93.
31. Miller FC, Spear M. "Very large-scale commercial trial of a biological control for mushroom blotch disease." Mushroom Science 1995;14:635-642.
32. Munsch P, Olivier JM, Houdeau G. "Experimental control of bacterial blotch by bacteriophages." In 13. International congress. AA Balkema, 1991.
33. Munshi, Nazir A, Gh Hassan Dar, Ghani MY, Shaheen Kauser, Najeeb Mughal. "Button mushroom cultivation." Edition: First Publisher: SK University of Agricultural Sciences and Technology of Kashmir Shalimar, Srinagar (J&K) India, 2010, 28
34. Muszyńska, Bożena, Agata Grzywacz-Kisielewska, Katarzyna Kała, Joanna Gdula-Argasińska. "Anti-inflammatory properties of edible mushrooms: A review." Food Chemistry 2018;243:373-381.
35. Nair NG, Macauley BJ. "Dry bubble disease of *Agaricus bisporus* and *A. bitorquis*, and its control by prochloraz—manganese complex." New Zealand Journal of Agricultural Research 1987;30(1):107-116.
36. Navarro, María J, Francisco Gea J, Ana González J. "Identification, incidence and control of bacterial blotch disease in mushroom crops by management of environmental conditions." Scientia Horticulturae 2018;229:10-18.
37. Paine, Sydney G. "Studies In Bacteriosis II1.: A Brown Blotch Disease Of Cultivated Mushrooms." Annals of Applied Biology 1919;5(3-4):206-219.
38. Palacios I, Lozano M, Moro C, D’arrigo M, Rostagno MA, Martínez JA *et al*. "Antioxidant properties of phenolic compounds occurring in edible mushrooms." Food Chemistry 2011;128(3):674-678.
39. Pehrsson PR, Haytowitz DB, Holden JM. "The USDA's national food and nutrient analysis program: update 2002." Journal of Food Composition and Analysis 2003;16(3):331-341.
40. Potočnik I, Milijašević S, Rekanović E, Todorović B, Stepanović M. "Sensitivity of *Verticillium fungicola* var. fungicola, *Mycogone perniciosa* and *Cladobotryum* spp. to fungicides in Serbia." In Science and cultivation of edible and medicinal fungi: Mushroom Science XVII, Proceeding of the 17th Congress of the International Society for Mushroom Science 2008, 615-627.
41. Pyck N, Grogan. "Fungal Diseases of Mushrooms and Their Control; Factsheet 04/15." 6.
42. Rainey PB, Cole ALJ. "A new bacterial disease of the cultivated mushroom, *Agaricus bisporus*." Transactions of the British Mycological Society 1988;90(1):122-125.
43. Romaine CP, Goodin MM. Unraveling the viral complex associated with La France disease of the cultivated mushroom, *Agaricus bisporus*. dsRNA Genetic Elements: Concepts and Applications in Agriculture, Forestry, and Medicine, 2001, 237.
44. Sante LN, Savoie J, Foulongneoriol M, Largeteau M, Barroso G. x Recent advances on bacterial disease of cultivated mushrooms. In Proceedings of the 7th International Conference on Mushroom Biology and Mushroom Products 2001, 4-7.
45. Shah S, Nasreen S, Kousar S. Efficacy of fungicides against Trichoderma spp. causing green mold disease of oyster mushroom (*Pleurotus sajor-caju*). Research Journal of Microbiology, 2013;8(1):13.
46. Sharma SR, Kumar S. "Studies on wet bubble disease of white button mushrooms (*Agaricus bisporus*) caused by *Mycogone perniciosa*." Studies on wet bubble disease of white button mushrooms (*Agaricus bisporus*) caused by *Mycogone perniciosa* 2000, 569-575.
47. Sharma SR, Satish Kumar, Sharma VP. Diseases and competitor moulds of mushrooms and their management. National Research Centre for Mushroom, Indian Council of Agricultural Research, 2007.
48. Sharma, Ved P, Sudheer Annepu K, Yogesh Gautam, Manjit Singh, Shwet Kamal. "Status of mushroom production in India." Mushroom research 2017;26(2):111-120.
49. Singh, Romi. "A review on different benefits of mushroom." IOSR Journal of Pharmacy and Biological Sciences 2017;12(1):107-11.
50. Sohi HS, Upadhyaya RC. "New and noteworthy diseases problems of edible mushrooms in India." Mush Sci 1989;12(2):611-614.
51. Soler-Rivas C. "Molecular aspects of the bacterial blotch disease of *Agaricus bisporus*." PhD diss., Ph. D. Thesis, University Claude-Bernard, Lyon, 1998.
52. Stanojević, Olja, Tanja Berić, Ivana Potočnik, Emil

Rekanović, Slaviša Stanković, Svetlana Milijašević-Marčić. "Biological control of green mould and dry bubble diseases of cultivated mushroom (*Agaricus bisporus* L.) by *Bacillus* spp." Crop Protection 2019;126:104944.
53. Fletcher T, John, Richard Gaze H. "Mushroom Pest and Disease Control: A Colour Handbook." 2019.
54. Tolaas AG. A bacterial disease of cultivated mushrooms. Phytopathology 1915;5:51-54.
55. Tsarev A. Dry bubble (fungus spot) or Verticillium disease. N.p., n.d. Web, 2014. (http://en.agaricus.ru/cultivation/diseases/).
56. Tsarev A Yellow Mould 2021. Retrived from the en.agaricus.ru.website:https://en.agaricus.ru/cultivation/diseases/yellowmould?fbclid=IwAR212HNd5aBeLTdWxF8eWgtk1lPgtq-2cFuX2xourkLeq4Vk49JgExfE29Ck
57. Umar MH, Geels FP, Van Griensven LJLD. Pathology and pathogenesis of *Mycogone perniciosa* infection of *Agaricus bisporus* 2000.
58. Wani, Bilal Ahmad, Bodha RH, Wani AH. "Nutritional and medicinal importance of mushrooms." Journal of Medicinal Plants Research 2010;4(24):2598-2604.
59. Wasser, Solomon P. "Medicinal mushroom science: history, current status, future trends, and unsolved problems." International Journal of Medicinal Mushrooms, 2010, 12(1).
60. Wasser, Solomon. "Medicinal mushroom science: Current perspectives, advances, evidences, and challenges." Biomedical journal, 2014, 37(6).
61. Young JM. "Drippy gill: a bacterial disease of cultivated mushrooms caused by *Pseudomonas agarici* n. sp." New Zealand Journal of Agricultural Research 1970;13(4):977-990.
62. Zhang M, Cui SW, Cheung PCK, Wang Q. Antitumor polysaccharides from mushrooms: A review on their isolation process, structural characteristics and antitumor activity. Trends in Food Science & Technology 2007;18(1):4-19.
63. Zhou, Chunyuan, Dan Li, Liangchen Chen, Yu Li. "Genetic diversity analysis of *Mycogone perniciosa* causing wet bubble disease of *Agaricus bisporus* in china using SRAP." Journal of Phytopathology 2016;164(4):271-275