Mushroom Pathogen Life Cycles as Related to Symptom Development

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Fungal Diseases

The life cycle for fungal pathogens like Dry Bubble, Trichoderma, and Cobweb is simple, Figure 1. Spores germinate into mycelium, which forms structures that produce spores. In a petri dish culture that may take less than a week; in compost or casing, it is probably pretty much the same. However, other factors like pH, moisture, and nutrient availability may influence this life cycle timing. Much of that, however, is unknown for these pathogens.

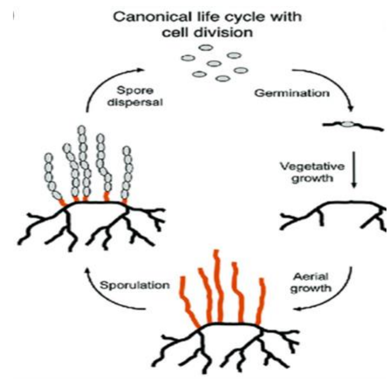

Figure 1 Typical fungal life cycle showing spores to fruiting. Source: researchgate.net

Looking at the disease cycle in mushroom cultivation, we know a relationship exists between spore load, time of infection, and symptoms or signs of disease development. Let's look at the three most common fungal diseases and what we know about these relationships.

Dry Bubble, caused by *Lecanicillium*, or *Verticillium* has symptoms that develop based on spore load and timing of infection. Spores coming in contact with a fully colonized spawn run don't germinate well and little disease will develop. It may be possible that spores landing on the substrate the day before or the day of casing could cause an early disease development. Spores in contact with the rhizomorphs in the casing will easily germinate. How fast they germinate, and the vegetative mycelium growth may be influenced by casing pH, moisture, relative humidity, and temperature. It is unknown what the optimum conditions are but in general the warmer the conditions the faster the growth and the shorter time from spore to symptom development. In general, spore to symptom takes about seven to 14 days depending on the above factors. However, when Dry Bubble mycelium is in contact with mushroom pins, metabolites are produced that degrade mushroom tissue. This process seems quick, perhaps hours to a day or two.

Dry Bubble Disease Cycle, Figure 2, shows how the disease starts and spreads around a mushroom farm. Infected mushrooms, usually found in later breaks, release spores that spread to other crops by vectors, such as watering equipment, flies or people. Spores land on the casing, germinate and the pathogen mycelium grows and infects mushroom tissue. Symptoms like necrotic spots can develop in as few as 12 hrs. when infected with a high spore load, but with a lower spore load

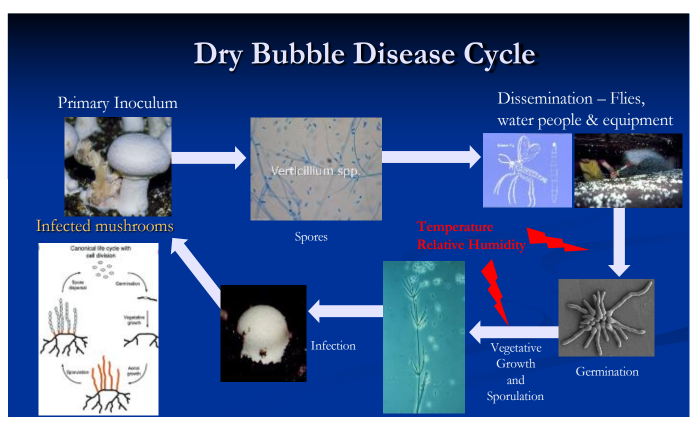

Figure 2 The disease cycle of Lencanicillium Dry Bubble disease.

spots develop in 48-96 hours. A heavy spore load that infects small pins will result in the classic dry bubble, whereas infection on a developing button will cause the split-stem symptom.

Figure 3 shows that the Trichoderma Green Mold Disease Cycle is similar to Dry Bubble although it is a faster-growing fungus in culture. It can cover a petri dish in just a few days. When a heavy Trichoderma spore load infects compost at spawning it can be found before casing. With a lower spore load Trichoderma may not be found until pinning after casing. Trichoderma development may be influenced by the availability of unprotected spawn grains or compost susceptibility. Low oxygen during Phase I or Phase II composting can leave an organic acid residual in the compost that favors the growth of Trichoderma.

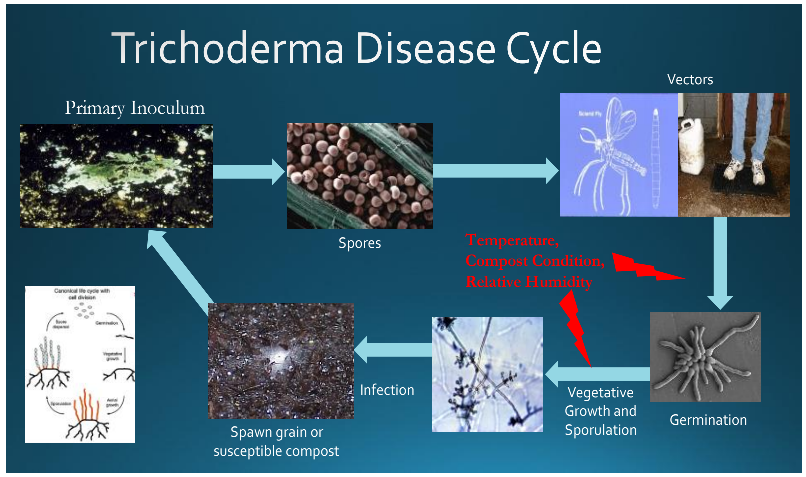

Figure 3 The disease cycle of Trichoderma Green Mold.

When infection occurs before casing Trichoderma can develop by the first break. Although it has been reported that Trichoderma spores will not germinate on fully colonized compost, Phase III compost broken up for filling at casing is very susceptible, in this instance Trichoderma may be found soon after casing. Spores infecting a crop after casing or during production could cause necrotic spot symptoms.

The life cycle of the fungal pathogen *Syzygites* (Hair, Barber, Bush Mold) is different than Dry Bubble or Trichoderma. It has two distinct cycles: sexual and asexual, Figure 4. The asexual cycle produces sporangiospores and the sexual cycle produces zygospores, Figure 5.

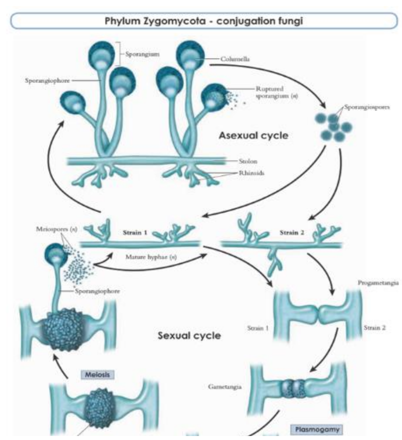

Figure 4 A typical life cycle of Mucorales fungus like Syzygies. Source: researchgate.net

The two types of spores are not only morphologically different but probably play different roles in disease development in a mushroom crop. Sporangiospores are small and attached to "sticky" sporangiophores, Figure 5a.

These spores are like *Lecanicillium* spores and are probably spread by people, equipment, and possibly flies. They seem to dislodge from the sporangiophore by watering or some other physical mechanism. But once they are dislodged, they are like Cobweb spores, light, fluffy and easily spread by air currents. When the spores or mycelium land on dead or fresh mushroom tissue they germinate, and symptoms develop. These spores are killed at temperatures below 100ºF, so they are unlikely to carry over from crop to crop.

Zygospores are the thick-walled, resting spore, part of the sexual cycle, but we are unsure of its role in disease development, Figure 5b. We are researching the isolation of these spores to determine the thermal death point and their ability to infect mushrooms.

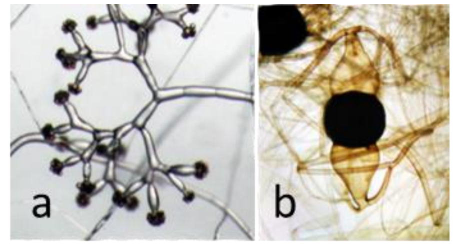

Figure 5 Two different spores are produced by Syzygites. 5a - Sporangiospores are small spores like Trichoderma and Lecanicillium fungi. 5b - Zygospores, larger thick-walled spores form the sexual cycle of this type of fungus.

The control of most fungal pathogens is based on minimizing the spore load, treating infected mushrooms or areas, and controlling or eliminating vectors to reduce secondary spore spreading. If possible, minimize favorable cultural conditions for *Syzygites* development by removing dead mushroom tissue from the beds and the floor.

LaFrance Virus Disease

Another interesting pathogen life cycle and disease development cycle is LaFrance Virus Disease (LVD). A virus inside the mushroom mycelium and tissue cells causes LVD. The virus life cycle is the replication of genetic material (RNA or DNA) inside these cells, Figure 6. We are unsure how long this takes, but it is a matter of minutes in this example. Therefore, it is likely that once a virus infects a healthy cell, it can replicate within that cell before that cell divides.

Several factors influence the time of symptom development and disease severity. Pete Romaine, who had studied viruses for over 25 years, reported that compost conditions play a role in the severity of this disease. Poor compost conditions include inadequate conditioning, with residual nitrogen compounds or overly wet compost with weak spawn growth. Other factors in LVD disease development include the time of infection and the quantity of virus-infected particles. A low spore load at filling or spawning may result in slight yield loss due to reduced mushroom size and weight. This infection may not show classic symptoms, like drumstick-shaped mushrooms, large bare areas, or dieback of the mycelium in the casing or compost. Romaine also suggested getting these classic symptoms takes a very high virus particle load.

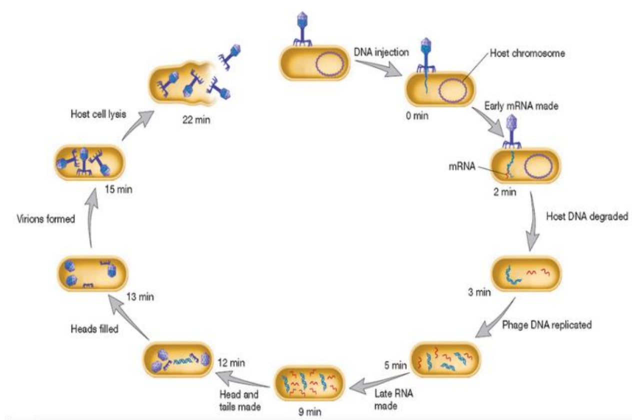

Figure 6 The typical life cycle of a virus that causes LaFrance Disease and shows how rapidly it can reproduce. Source: phagesaga.weebly.com

Low particle infection may create mild symptoms that often appear as water mismanagement where pins don't form or develop in patchy areas on the beds. The random appearance of spindly mushrooms may look like an elevated carbon dioxide level and not like a classic virus symptom.

Control of LVD should be focused on stopping the spread of virus-infected spores and mycelium. It starts with reducing open mushrooms on the beds for the white button mushrooms, obviously not an option for Portabella growers. For traditional farms with wooden trays and bed shelves, a complete and thorough post-crop steaming is needed. The wood and nets should be washed and then steamed to eliminate any infected mycelium. This complete post-crop would include steaming the rooms empty.

Spawning and casing operations need to be protected from virus-infected spores and in Phase III operations from virus-infected mycelium. Filtered positive-pressure air should be used during these operations when possible. Additionally, positive pressure should be reduced in the harvesting rooms to decrease the number of virus-infected spores escaping the room. Using HEPA filters on all the HVAC units is a good practice, as is preventing cross-contamination of rooms that have a common drain system.

Bacterial Blotch

The life cycle of the bacterium (*Pseudomonas* spp.) that causes bacterial blotch influences disease development and severity. Its life cycle is relatively simple and quick, Figure 7. The genetic material within the bacteria divides and then the cell divides, this life cycle is complete in a matter of hours. This fast reproduction rate explains why bacterial blotch can develop symptoms under ideal conditions in just a few hours.

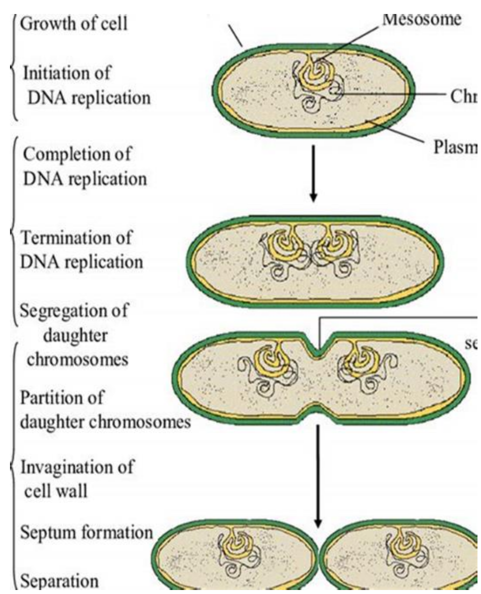

Figure 7 Typical life cycle of a bacteria like Pseudomonas, that cause Bacterial Blotch disease. Source: researchgate.net

The symptoms that develop and how fast they develop will depend on the population of bacteria on the mushroom tissue. The population will develop rapidly if mushroom surface tissue is moist. A high bacterial population is needed to get symptoms, and the more bacteria the quicker the symptom development. The incubation time can be as little as one to two hours and under ideal conditions symptoms can develop in three to six hours.

Another factor in disease severity is the time these bacteria are living on mushroom tissue. *Pseudomonas* bacteria become "pathogenically" adapted to the mushroom and that explains why when there is blotch on the first break it often is more severe on both the second and third breaks.

Bacterial blotch control is about keeping the mushroom's tissue as dry as possible from pinning through harvesting. Controlling the dew point, relative, and absolute humidity in the room and around the developing mushrooms is critical. Water additives like chlorine, chlorine dioxide, and calcium chloride are helpful, but in my opinion, are most effective when the mushrooms are quickly dried after irrigation. A staggered first break pin development helps air circulation around the developing mushrooms and reduces the number of mushroom caps touching each other, where moisture will collect.

Summary

Knowing a pathogen's life cycle and how it influences the disease cycle and development will help growers control these diseases. A good understanding of how specific symptoms indicate the time of infection, and the severity of these symptoms, may provide an indicator of spore loads around the farm. Most control methods are focused on breaking the disease cycle by reducing the spread of the pathogen or reducing cultural conditions that encourage its growth.