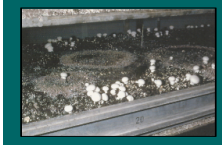

MUSHROOM PEST & DISEASE

MU16003 fact sheet #3

Penicillium hermansii – Smoky mould

GROWERS' NOTES

- Smoky mould is caused by *Penicillium hermansii*.
- Smoky mould can be prevented by producing a highly selective compost, effective physical exclusion and stringent hygiene.
- Smoky mould spores may survive pasteurization in dry areas of compost.
- Incoming air to conditioned Phase II compost must be filtered.
- Phase II compost, Phase III compost, spawning and room fill are susceptible to infection.
- Spawning and room emptying must not occur at the same time.
- Cookout is an effective control measure against *P. hermansii*, but some spores may survive in dry areas of compost.
- One *Penicillium* colony can produce 400,000,000 spores per day.

INTRODUCTION

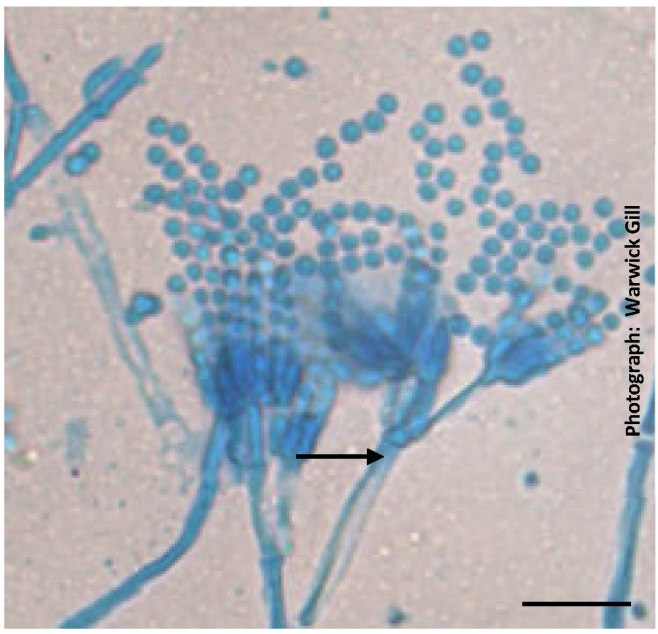

Figure 1 Long chains of small dry spores produced on numerous conidiophores (arrow). Scale bar = 10μm

Smoky mould is a destructive compost infection first recognized in the Netherlands nearly 30 years ago. Despite being identified as various *Penicillium* species over the years, the true identity of the causal organism has only recently been confirmed through molecular analysis as *Penicillium hermansii*.

Penicillium species produce long chains of very small, lightweight, dry spores which are around 0.002mm in diameter (Fig. 1) and become airborne very easily. A single *Penicillium* colony (Fig. 2) will produce 400,000,000 spores per day. Although *P. hermansii* is very slow growing, it is problematic because of the large number of spores it produces and its short generation time. *Penicillium hermansii* will sporulate only three or four days after infection, producing thousands of daughter colonies which in turn sporulate rapidly.

When non-productive areas of smoky mould-affected compost are disturbed, so many spores are released into the air that they appear as a cloud of smoke, hence the common name of this disease.

Figure 2 A 7-day-old culture of *P. hermansii* growing on a nutrient agar. *Photograph: adapted from Houbraken et al (2019) and reproduced with kind permission from SpringerLink according to the terms of the Creative Commons Attribution 4.0 International License*

The impact of smoky mould on mushroom yield is variable. Minor infections may go completely undetected while severe outbreaks cause yield reductions of up to 80%. Losses from infection of Phase II compost typically range from 5 – 15%, but in

experimental trials, smoky mould infection reduced yields by up to 90% and in some instances, total crop failure was recorded, indicating the devastating potential of this disease.

Although this pathogen appears to be in tune with modern cultivation practices, it is not very common because smoky mould requires a very high level of inoculum to establish a significant infection.

SYMPTOMS

The range and degree of smoky mould symptoms expressed is dependent upon the amount of the inoculum and the time of infection. Generally, early infection of Phase II compost or a large inoculum will result in a more severe symptomology. Symptoms range from a slight yield reduction through to completely non-productive beds which produce no mushrooms. Severely affected beds also produce clouds of spores when the non-productive compost is disturbed.

In light infections, smoky mould may go undetected but for a slight reduction in third flush yield. Affected mushrooms may appear pale and opening may be early.

Mild outbreaks are marked by a reduced yield in first and second flush with areas of non-cropping compost developing by third flush. Poor quality mushrooms predominate by third flush in which sparse early opening fruit form small pale flats of little or no commercial value.

In severe outbreaks (Fig. 3), large bare areas develop on the first flush bed or the entire bed may be devoid of mushrooms. In the patches that do produce, mushrooms are sparse, have thin spongy stalks and small caps which tend to split. Mushrooms overall appear to be weak and fragile due to the lack of nutrition. The characteristic symptom, smoke-like clouds of spores rising from the affected bed, is associated with the patches of non-productive casing. If the casing within a non-productive area is moved to one side and a handful of the underlying compost is lifted and removed, the upper portion of unproductive compost may appear darker. The *Agaricus* mycelium is totally absent or reduced compared to the lower compost levels. When the handful of compost is broken open, clouds of airborne spores are released which, in the beam of a flashlight, look like smoke rising from the bed.

Figure 3 Poor spawn run and reduced fruiting in the left hand tray is due to smoky mould infection. *Photograph: Fletcher & Gaze (2008)*

DISEASE DEVELOPMENT

The origin of smoky mould infection is uncertain but *P. hermansii* is thought to enter the mushroom cultivation system in soil, on dirty straw or by contamination of compost preparation surfaces. *Penicillium hermansii* spores introduced into Phase II compost directly on contaminated straw are spread throughout the entire compost batch during preparation, mixing and handling and by the action of forced air in the tunnel. Standard pasteurization conditions are sufficient to kill smoky mould spores, but if dry straw is used or the substrate is not sufficiently mixed, *P. hermansii* spores can survive in dry pockets of compost. After cooldown, Phase II compost is susceptible to smoky mould and infection at this stage, primarily from contaminated Phase III compost on the same site, will lead to serious problems in subsequent crops.

Figure 4 *Penicillium hermansii* growing and sporulating on compost. The fluffy conidiophores produce spores which become grey/green. *Photograph: Anonymous, Mushroom Business (2018)*

Although many *P. hermansii* spores may be present within Phase II compost, the mould will only grow once the compost has been spawned and the mushroom mycelium begins to grow (Fig. 4). With an optimal temperature of 28-31°C, spawn run provides *P. hermansii* with the ideal environment to compete with mushroom mycelium. In the early stages of spawn run, *P. hermansii* hyphae grow alongside *Agaricus* hyphae, but at some stage smoky mould mycelium displaces and severely inhibits mushroom mycelium and takes over the compost.

Smoky mould infection may also occur as Phase III compost is filled into a grow room. Spores released from infected beds elsewhere on the farm can contaminate the compost as it is mixed and the *Agaricus* mycelium is broken up. *Penicillium hermansii* spores will germinate and then feed off the simple carbohydrates leaked from the damaged *Agaricus* hyphae. If Phase III compost is extensively colonised by *P. hermansii* at delivery, it will appear entirely normal as the pathogen mycelium is indistinguishable from the mushroom mycelium.

As *P. hermansii* grows, its high metabolic rate increases the compost temperature and the first sign of smoky mould infection may be an uncontrollable rise in compost temperature which cannot be reduced even with extremely cold air. The elevated temperature kills the *Agaricus* mycelium, resulting in areas of non-productive compost. The increased temperature also stimulates growth of more heat-tolerant moulds present within the compost and casing, such as cinnamon mould (*Pezziza ostracoderma*), which may subsequently colonise the non-productive areas of infected beds (Fig. 5).

Figure 5 Mushroom formation around the edge of the bed due to smoky mould infection and non-productive areas of casing colonized by cinnamon mould. *Photograph: Fletcher & Gaze (2008)*

Smoky mould spores are primarily spread by air currents. Spores released into the air when the compost is disturbed, usually during standard cultivation practices such as watering, harvesting and spot treatment, are spread around the farm by moving air. Because of the biology of the *Penicillium* spore, common vectors like mites and flies are not thought to be as significant in the spread of smoky mould as they are in diseases which produce sticky spores such as dry bubble (*Lecanicillium fungicola*).

DISEASE MANAGEMENT

Prevention, achieved by providing a highly selective homogenous compost with the correct moisture content, effective physical exclusion and stringent hygiene practices, is the most effective control for this disease (Table 1). Once smoky mould infection has established, there are no remedial treatments available. There are no fungicides available in Australia with a registered use pattern effective against *P. hermansii*. Should smoky mould express in a crop, the only control available is to reduce the temperature in the growing room to limit the spread of the disease and to reduce the water content of the compost, as infection worsens in wet compost.

The small spores of smoky mould are susceptible to heat, so standard Phase II parameters – 8-10 hours at an air temperature of 56°C and gaseous ammonia at 450ppm for 3 hours after peak heat is achieved – are sufficient to eradicate the organism. However, spores will survive Phase II if the substrate is poorly mixed.

During cooldown, incoming air to Phase II tunnels and buildings must be filtered and the building integrity secured to minimise the number of spores entering. Filters must be inspected routinely and replaced as necessary, while the building must be monitored regularly to check for cracked door seals and structural damage that may allow spores entry to the conditioned compost.

On compost facilities that have a smoky mould problem, spawning and emptying Phase III tunnels must be separated physically and the operations scheduled apart. Similarly, farms that spawn run in trays are also vulnerable to infection at spawning and it is important that spawning and room emptying are not done at the same time. While cookout of infected compost for 8 hours at 70°C will kill most spores, it is still possible that some may remain viable in dry pockets within the compost and become airborne when the room is emptied.

In both types of facilities, the immediate vicinity of the spawning area must be sanitised before operations and if possible, be performed under positive pressure. During fill, the area around the new grow room must be kept scrupulously clean throughout the operation and the emptying of terminated crops must not be undertaken at the same time. Farms that are unable to cookout must ensure that the potentially infected crop is terminated correctly and that it is not removed from the room at the same time spawning is underway.

Table 1 Checklist of key action points for smoky mould prevention and control

Location	Check	Action points
Phase II and III operations	☐	Phase II spawning halls are separated from Phase III emptying areas
	☐	Spawning & Phase III emptying are not carried out at the same time
	☐	Spawning equipment cleaned & disinfected immediately before & after use
	☐	Machinery handling Phase II & Phase III compost is not shared
	☐	Phase III tunnels, shelves & trays in which spawn-run is performed are steamed before re-use
Filtration and air pressure	☐	The filtration of Phase II & Phase III facilities is maintained at the highest standard • ingress of unfiltered air is avoided by installing the highest possible grade of HEPA filters • filters and ducts are regularly maintained
	☐	Spawning halls are held at positive pressure with filtered air
	☐	Phase III emptying halls are held at neutral pressure
	☐	If grow rooms are infected, filter cropping room exhausts or, turn off air in the grow room during fill if grow rooms exhaust to filling areas
Filling and casing	☐	Casing stored under protection
	☐	Spawned compost is covered before & after filling
	☐	Filling and casing equipment thoroughly cleaned & disinfected immediately before each use to avoid re-infection
	☐	Filling & casing carried out in dust-free conditions
	☐	Filling & casing personnel isolated from other farm staff before operations begin
	☐	Blocking & bagging equipment thoroughly cleaned & disinfected to prevent mycelial carry over
	☐	Spilt compost & casing is cleaned up after operations with low pressure water & squeegee
Grow room	☐	Grow room doors kept closed during filling; do not harvest, clean or empty rooms during filling
	☐	Waste mushroom material, butts & stalks are disposed of appropriately
	☐	Grow room, floors, shelves, netting & walls washed then disinfected after emptying
	☐	Concrete outside the grow room washed & disinfected
Cook out	☐	All crops cooked out *in situ* at termination (compost held at 70°C for minimum of 8 hours)
	☐	Spent compost removed from site as soon as possible
Monitoring	☐	Building integrity monitored at regular intervals
General	☐	Buildings, roadways and all concrete areas are disinfected daily
	☐	Returnable plastic containers cleaned between uses
	☐	Farm maintenance kept up: rooms & smooth surfaces in good condition are easier to keep clean
	☐	Accumulation of organic matter around the farm which can act as source of infection cleared away

Adapted from Gaze & Grogan (2007), Fletcher & Gaze (2008) and Fleming-Archibald *et al* (2015)

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FOR FURTHER INFORMATION, CONTACT:

Judy Allan
judyallan@bigpond.com
(02) 6767 1057

Warwick Gill
warwick.gill@utas.edu.au
0417 766 588

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