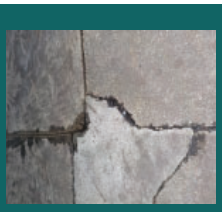

MUSHROOM PEST & DISEASE

MU16003 fact sheet #5

Getting the best from your cookout

Introduction

As mushroom crops mature, pest and pathogen levels increase so that by the end of the crop, the pathogen population reaches its maximum (Fletcher & Gaze 2008). Effective crop termination is essential to reduce the pathogen population, allowing the next crop to 'start clean' and to break the cycle of diseases, such as Dry Bubble, which are perpetuated by continual on-farm re-infection.

By far the most effective termination procedure is cookout *in situ,* where the crop is treated undisturbed in the grow room with steam. An effective cookout prevents contamination of subsequent and adjacent crops which occurs when spent substrate contaminated with viable pathogens, pests and their larvae is removed from a grow room (Beyer 2018).

Cookout must kill pests and pathogens within the compost and netting on shelf farms and within the compost and tray timbers on tray farms. Cookout must also kill *Agaricus* mycelium and spores within the compost and tray timbers to prevent spread of virus diseases.

Why is steam used for cookout?

Heat is one of the oldest and most common methods used to control microbial growth. It is still the most reliable form of pest and pathogen control available as it physically and irreversibly destroys the enzymes and other cell components essential for life.

There are two basic forms of heating – dry heat and moist heat. Dry heat transfers energy by radiation and does not penetrate very well. This is problematic when dealing with tonnes of dense compost, casing and tray timbers. Because of the lack of penetration, dry heat requires a higher temperature and a longer exposure time to achieve the same kill as moist heat, requiring more energy and higher costs to do so.

Furthermore, dry heat is not practical for the large volume of air in a mushroom grow room and the higher temperatures or prolonged exposure required will be damaging to the room structure. On the other hand, steam transfers heat through conduction, which penetrates the compost much more efficiently. Steam also contains a large amount of latent heat which is readily transferred to the compost as it condenses on cooler surfaces.

Thermal death time

To achieve an effective kill of mushroom pests and pathogens, the crop must be exposed to steam for the correct combination of time and temperature. Two terms – **thermal death point** (TDP) and **thermal death time** (TDT) – are often used interchangeably to describe the effect of the combination of temperature and time, but they refer to different things.

By definition, the TDP of a microorganism is the lowest temperature at which all microbes are killed in a 10-minute exposure whereas the TDT is the time needed to kill all microorganisms in a sample at a given temperature. Both parameters are derived from and are significant to the food industry where there is a fine line between making food safe from human pathogens and retaining the desired texture and composition of the food.

But in terms of the mushroom farm cookout, the more appropriate parameter to use is TDT where a room is treated with steam at a set temperature for a time that is sufficient to kill all the pests, pathogens and mushroom spores present in the compost and the grow room environment.

Different organisms have different TDTs. Because the majority of mushroom pest and pathogen TDTs have been determined on the laboratory bench under different conditions, there is a lot of variation in the results reported over many years.

To be effective, the conditions of cookout must encompass the TDTs of all the different pests and pathogens that are present or are likely to be present as listed in the **Table of Thermal Death Times** (overleaf). As illustrated by the table data, a lower temperature requires a longer exposure to achieve the same kill.

Because the TDTs of pests and pathogens are critical to disease control and because the Project Team are regularly asked for the TDTs of different pests and pathogens, this information has been presented here as a ready-reference table on a single page that can be printed out and posted in a prominent place on your farm or kept on file for when it is needed.

Thermal Death Times of Some Mushroom Pests and Pathogens

Pest/Pathogen	Temp	Time to Kill
Phorid larvae (*Megaselia*)	55°C	5hr
Phorid adults (*Megaselia*)	55°C	5hr
Sciarid larvae (*Lycoriella* & *Bradysia*)	55°C	5hr
Sciarid adults (*Lycoriella* & *Bradysia*)	55°C	5hr
Cecid larvae (*Mycophila*, *Heteropeza* & *Henria*)	46°C	1hr
Cecid adults (*Mycophila*, *Heteropeza* & *Henria*)	46°C	1hr
Mites	55°C	5hr
Nematodes	55°C	5hr
Dry Bubble (*Lecanicillium*)	60°C	2hr
Dry Bubble (*Lecanicillium*)	55°C	4hr
Cobweb (*Cladobotryum*)	50°C	4hr
Cobweb (*Cladobotryum*)	60°C	2hr
Wet bubble (*Mycogone*)	50°C	4hr
Wet Bubble (*Mycogone*)	60°C	2hr
Lipstick mould (*Sporendonema*)	50°C	16hr
Lipstick mould (*Sporendonema*)	60°C	6hr
Brown plaster mould (*Papulospora*)	60°C	4hr
False truffle (*Diehliomyces*)	60°C	A few hours
Olive green mould (*Chaetomium*)	60°C	6hr
Mat disease (*Chrysosporium*)	60°C	2hr
Mat disease (*Chrysosporium*)	50°C	16hr
Bacterial blotch (*Pseudomonas tolaasii*)	50°C	10min
Mushroom spores (*Agaricus*)	70°C	3hr
Mushroom spores (*Agaricus*)	65°C	72hr

Overstijns (1998)

Determining effective cookout parameters

There are many variables on-farm which account for differences in the TDTs determined in the laboratory and those recommended in practice, such as:

- rate of heat penetration
- uniformity of heat penetration
- substrate density
- substrate moisture content
- compost structure
- production system – trays or shelves
- age of the farm infrastructure
- integrity of grow rooms
- numbers of pests and pathogens present
- resistance of dry spores

some of which may or may not be interdependent.

All variables considered, for a modern shelf farm, holding the room for a minimum of nine hours at a compost temperature of 65-70°C is sufficient, which is well above the TDTs established for individual mushroom pests, pathogens and mushroom spores.

This extra time allows the steam to penetrate deeply into wet, dense compost and casing and to treat areas that may be difficult to heat, such as cracks and joins in concrete floors.

For an older farm using timber trays, there will often be issues with wall integrity, door seals (Fig. 1) and boiler efficiency resulting in increased heat loss and less uniform heating. The time and temperature may need to be increased to 70°C for 12 hours or more to mitigate any temperature fluctuations and loss of steam due to the aging infrastructure (Table 1).

Furthermore, the condition of the pathogen is also influential on the efficacy of cookout. Dry fungus spores are more difficult to kill than fresh spores; fresh Cobweb spores (*Cladobotryum* spp.) are killed at a temperature of 45°C for 30 minutes but can tolerate up to 100°C when dry. Similarly, fresh mycelium is killed at 40°C for 15 minutes, but dry mycelium can stand 70°C for 15 minutes.

Cookout

Once the crop and the room are prepared for cookout and temperature probes are in position, steam is injected into the room under pressure (Fig. 2) and the air temperature is raised carefully to avoid structural damage to the room. The compost is brought up to target temperature and held at that temperature for the required time to achieve an efficient kill.

Figure 1 Steam escaping through inadequate door seals. *Image: Judy Allan*

Table 1 Recommended cookout parameters

Condition	Temp (°C)	Time	Reference
Routine cookout	66	12 hours	Beyer (2018)
if under high disease pressure, re-steam empty room	66	24 hours	
Routine cookout	65-70	8 hours	Pyck & Grogan (2015)
re-steam sanitised nets	65	2 – 8 hours	
Routine cookout	60-70	8 – 24 hours	Curtis (2008)
Under high disease pressure, initial cookout	65	24 hours	
then re-steam empty room with netting	65-70	12-24 hours	
or re-steam empty room with timber trays	75	6-12 hours	
Routine cookout	65-70	9-12 hours	Fletcher & Gaze (2008)
on older farms (heat loss and less efficient heating)	70	12 hours	
re-steam trays to clean once substrate removed	60	6 hours	
Routine cookout incorporating propiconazole treatment	70	A few hours	Catlin *et al* (2004)
Routine cookout	70	12 hours	Geels *et al* (1988)
Routine cookout	70	10 hours	Hayes (1978)

Figure 2 Steam being introduced at the end of third flush. *Image: Judy Allan*

After cookout, grow rooms should be emptied downwind from new rooms and an old crop must never be emptied while filling or casing operations are underway in adjacent rooms. The concrete apron outside a grow room should be washed down thoroughly each time it is filled or emptied and the area outside the newly filled room must be kept clear of organic debris (Curtis 2008).

Irrespective of the effectiveness of cookout, the correct handling of spent mushroom compost (SMC) after cooldown is crucial in maintaining on-farm biosecurity. SMC must be removed from the farm at the earliest opportunity. If the cookout has not totally eradicated pests and diseases, then stockpiling SMC on-farm has the effect of merely shifting a significant disease reservoir from the grow room to the farm environment, exposing the entire farm to contamination.

Even if cookout has been totally effective and all pests, pathogens, *Agaricus* mycelium and *Agaricus* spores within the compost and casing have been destroyed, dumping SMC within the farm environs still poses a major risk. An effective cookout reduces the SMC to a microbiological 'void'; there is nothing living within the treated compost. Therefore, pathogenic fungi and pests are able to easily contaminate the still highly nutritious SMC as there are no competitive organisms, particularly *Agaricus* mycelium, to discourage colonization. The longer SMC is left on-farm, the greater the reservoir of pests and diseases that builds up. It is therefore essential that SMC, under all circumstances, is removed immediately from the farm environment and not stockpiled on the property.

Within a farm's integrated pest and disease management system, cookout is a single, albeit very effective step. Even after an effective cookout and removal of SMC, the grow room must still be thoroughly cleaned and sanitized to eradicate those pests and pathogens that may have avoided the effects of heating by being sheltered in locations such as floor cracks and joins. Effective grow room sanitation is not a simple process – there are seven recognised steps to cleaning a grow room before it is filled with the new crop (Curtis 2008).

1. *Gross cleaning:* this is the removal of soil, mushroom debris and other organic material using a squeegee, shovel and water. Failure to perform this step adequately is the most common cause of the breakdown in grow room hygiene. Any residual organic material will reduce the efficacy of disinfectants and sanitizers used in later steps and provide a growing niche for contaminants including mushroom pathogens. Avoid using pressure cleaners or high-pressure water as aerosols will remain suspended for a time before falling out onto cleaned surfaces.
2. *Pre-rinsing:* pre-rinsing removes organic deposits not easily removed by gross cleaning and should be undertaken from the top of the room to the floor with a high volume of low-pressure water.
3. *Detergent application:* detergents can be applied manually by brush, broom or cloth or mechanically as a spray or foam, but physical effort such as scrubbing is often required to dislodge soil depending on the surface texture. Be aware that when manually applying detergent, repeated dipping the brush, broom or cloth into the bucket of detergent will reduce the effectiveness of the detergent by increasing the organic load in the bucket. Fresh solutions must regularly be made, or the brush, broom or cloth must be rinsed before returning to the bucket.
4. *Post-rinsing:* this process, utilising high volume low-pressure water at a temperature less than 50°C, removes detergent residue which will reduce the efficacy of subsequent disinfectants. Using water greater than 50°C introduces the possibility of creating steam and aerosols. Following this step, standing water ought to be removed from the floor to prevent the dilution of disinfectants and sanitizers.
5. *Disinfection:* disinfectants should only be applied to dry surfaces free of visible soiling either manually or mechanically (spraying or fogging). Caution must be taken when fogging a disinfectant to ensure the safety of farm staff. Confirm that the product label states the disinfectant is appropriate for fogging.
6. *Terminal rinsing:* this is particularly important if the disinfectant applied is corrosive or if the disinfectant has been applied to food-contact surfaces. Check the disinfectant label for the requirement to rinse and the required contact time. These requirements must be followed to maximise disinfectant efficacy.
7. *Drying:* disinfected surfaces retain their hygienic state longer if allowed to dry. Leave doors and vents closed during drying to prevent contamination.

Trichoderma – a special case

If a farm is under high disease pressure, then cooking out a room both before and after the substrate is removed is recommended (Table 1). *Trichoderma* is able to survive routine cookout conditions. Rinker (1996) reported isolating *Trichoderma harzianum* from compost and production room floors following routine cookout. After trialling combinations of heat and time, it was shown that a temperature exceeding 65°C for at least five hours out of a total of 20 hours eradicated the green mould pathogen.

Further work reported by Rinker & Alm (2000) demonstrated that *T. aggressivum* was able to survive compost

temperatures of:

- 73°C for 18 hours
- 74°C for 29 hours
- 77°C for 17 hours
- 60-65°C for 20 hours

but was destroyed when exposed to a compost temperature of 68°C for 42 hours.

It has since been demonstrated that T*richoderma aggressivum* f. *aggressivum* (the North American variant of *T. aggressivum*) is able to penetrate tray timbers and survive routine cookout while the substrate is *in situ* (Catlin *et al* 2004). Only after the substrate is removed and the trays cleaned and steamed again are persistent pathogens eradicated. Treatment of trays with the fungicide propiconazole (Safetray® P containing 250g/L propiconazole is registered by the APVMA for use on mushroom trays in Australia) reduced penetration of the timber by *T. aggressivum.* The isolation frequency of the green mould pathogen following cookout was reduced by 80% (Catlin *et al* 2004). No matter how high or how rapidly the air temperature is raised at first, it still takes about 14 hours for the substrate to reach 60°C. On tray farms, depending on the timber used, it may take the trays five to six times longer to attain lethal temperature than it does the substrate (Beyer 2018). This highlights the potential for disease carry-over in tray timbers and the need for a second steam when the farm is under disease pressure.

On farms that cookout in a dedicated steam room, the preparation differs slightly. Before transfer, the room fans must be turned off and the crop treated with a disinfectant. The room must then be shut down for 1 hour to allow disturbed spores to settle before moving, to reduce the chance of spreading pathogens around the farm environment (Fletcher & Gaze 2008). This procedure must not be carried out while another room is being filled.

Consequences of a short cookout

Growers are under pressure to reach projected yields and to satisfy market demand within strict timeframes. Grow rooms which used to be cooked out one week and filled the next, are now being turned over in a matter of hours, not days, to meet tight production schedules. Consequently, cookout is often reduced to save time, yet the consequences of a short cookout may have a significant impact on yield and quality by not achieving a satisfactory kill.

Growers using timber trays face challenges not experienced by the shelf grower. The tray timbers are capable of harbouring pathogens like *T. aggressivum*, which can survive even strenuous cookout, and also virus-transmitting *Agaricus* mycelium and spores. An insufficient cookout on a tray farm will invariably lead to a build-up of pathogen inoculum within the timber.

With a reduced cookout, an unrealistic expectation is then placed on the effectiveness of sanitizers and disinfectants used to sanitize the room post-cookout. The mushroom farm environment is invariably rich in organic debris and standing water, two factors which are known to significantly reduce the efficacy of sanitizers. The reduction in efficacy due to the extra organic burden imposed on sanitizers and disinfectants by a reduced cookout is made worse by growers overlooking the withholding periods and contact times stipulated by product manufacturers. These recommendations are often not compatible with rapid room turnover and tight production schedules. Not only does this practice compromise crop biosecurity, but it also introduces the potential for chemical residue accumulation in mushrooms.

Floors, floor cracks and floor joins (Figs 3, 4) provide a haven for pathogens from routine cookout. The concrete floor acts as a heat sink, drawing heat from the atmosphere during cookout and transferring it to the ground. Consequently, the floor may never reach an adequate temperature for the required kill time. As recent evidence has indicated (Gill 2017), pathogens will survive within the compacted organic matter or beneath the join filler and establish a carry-over reservoir, even after a routine cookout. These locations are particularly significant following a reduced cookout. And because heat leaks from the walls into the floor, the bottom of the walls and the wall/floor join are also critical locations for potential pest and disease reservoir carry-over.

Figure 3 Floor cracks effectively harbour pests and pathogens during cookout. *Image: Warwick Gill*

Figure 4 Pests and pathogen reservoirs can form in both unfilled (above) and inadequately filled floor joins. *Image: Warwick Gill*

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