Figure 1. Mushroom phorid on a mushroom cap

PHORID ECOLOGY AND MANAGEMENT

by **Dr Jenny Ekman**

Flies in mushroom crops are a persistent, annoying, and occasionally, very damaging issue that all growers will face at some time.

Most research has focussed on sciarids (*Lycoriella* spp.), often the most common species present. The maggots feed on organic matter in compost and readily adapt to captivity, making research relatively easy.

Mushroom phorid flies may be a minor problem on most Australian farms, but in many countries – including Spain, Turkey, India, the UK and the US – they are a major pest. Yield losses of 10 to 40% have been widely reported[1]. Some Australian farms are now also reporting persistent populations of these flies.

Unlike sciarids, phorid maggots feed directly on the *Agaricus* mycelia, potentially affecting both yield and quality.

Apart from direct crop damage, phorids are pathogen vectors, particularly dry bubble disease (*Lecanicillium fungicola* var. *fungicola*). This fungal parasite produces masses of conidia covered with sticky mucilage that readily sticks to tiny fly feet[2]. Brown blotch bacteria and mites can also be spread by flies moving around the grow room.

High populations of phorids (or any fly species) are also a significant nuisance in growing rooms. Getting and keeping good staff is difficult enough without asking them to pick mushrooms in a cloud of annoying flies.

Then there are the issues with the neighbours. In a recent MushroomLink podcast, Geoff Price from Giorgi Mushroom Co. Penn State commented on this issue in the US.

"The whole community here is up in arms about the phorids, it's become a big problem."

1 Navarro MJ, Escudero-Colomar LA, Carrasco J, Gea FJ. 2021. Mushroom phorid flies – A review. Agronomy: 11:1958. https://doi.org/10.3390/agronomy 11101958

2 Gea FJ et al. 2021. Control of fungal diseases in mushroom crops while dealing with fungicide resistance: A review. Microorganisms, 9:585.

Figure 2. Phorid flies on mushrooms infected with dry bubble. From Navarro et al., 2021.

"There are a lot of mushroom farms here, but also a lot of expensive housing. In summer, when people are outside, they can get really clobbered".

New research has been investigating phorid biology, ecology, and the best ways to manage these annoying pests.

LIFE CYCLE

The phorid *Megaselia halterata* has been considered a significant mushroom pest since 1953, when population explosions occurred in British mushroom farms. While there are other *Megaselia* species which can also cause problems, particularly *M. nigra*, *M. halterata* is an *Agaricus* and *Pleurotus* specialist not found on other fungal hosts.

Female *M. halterata* are strongly attracted to growing *Agaricus* mycelia. The more mycelia present, the stronger their response. They are therefore more attracted to Phase III compost than compost which has been recently spawned[3].

Each female can lay at least 50 eggs during her lifecycle. These are deposited close to growing mycelia, so primarily in the top layer of Phase III compost. Eggs are also laid in casing if it has been colonised by the mycelium; flies do not lay into freshly applied casing[4].

The maggots feed on *Agaricus* mycelia until they are fully mature, after which they migrate upwards into the top of the compost or casing and pupate. Males tend to emerge before females, with both sexes being ready to mate around five days after emergence.

Temperature vs time

Temperature is a key determinant of development rate for all insects, and phorids are no exception. Development slows markedly once temperatures fall below 18°C[5]. As a result, it takes twice as long for flies to complete their lifecycle at 15°C compared to 18°C (Figure 4).

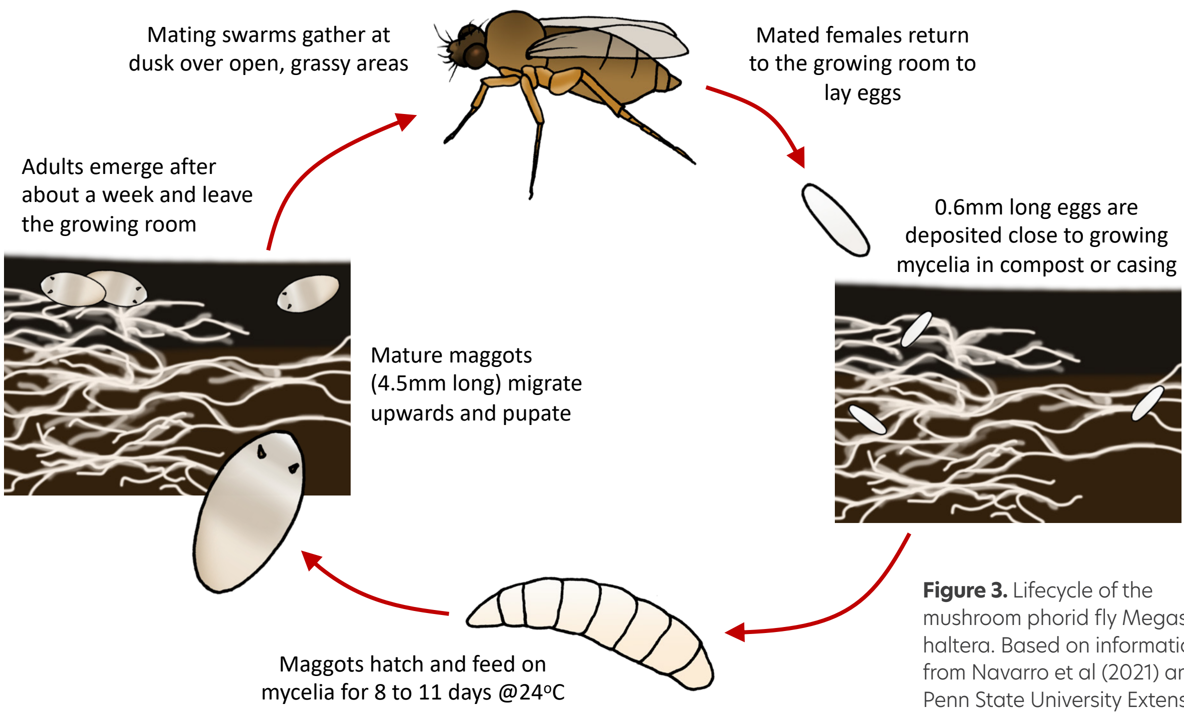

Figure 3. Lifecycle of the mushroom phorid fly Megaselia haltera. Based on information from Navarro et al (2021) and Penn State University Extension

3 Tibbles LL et al. 2005. Evaluation of the behavioural response of the flies Megaselia halterata and Lycoriella castanescens to different mushroom cultivation materials. Entomol. Exp. Applic. 116:73-81.

4 Scheepmaker JWA, Geels FP, Smits PH, Van Griensven LJLD. 1997. Location of immature stages of the mushroom insect pest Megaselia halterata in mushroom growing medium. Entomol. Exp. Applic. 83

5 Barzegar S et al., 2016. Temperature dependant development modelling of the phorid fly Megaselia halterata (Wood)(Diptera: Phoridae). Neotrop Entomol. 45:507-516.

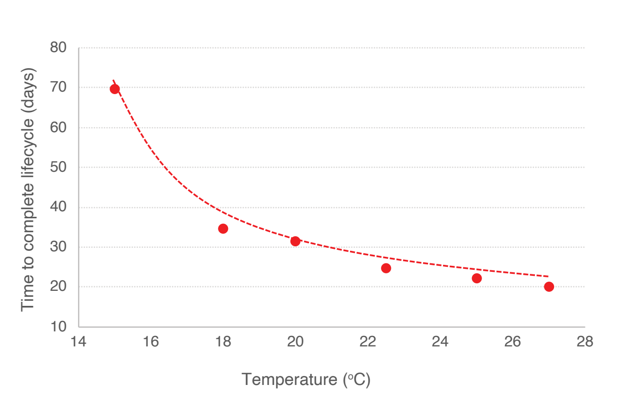

Figure 4. The development rate of phorids from egg to adult fly increases as temperatures rise, so populations can grow rapidly at temperatures 20°C or more. Derived from Barzegar et al., 2016.

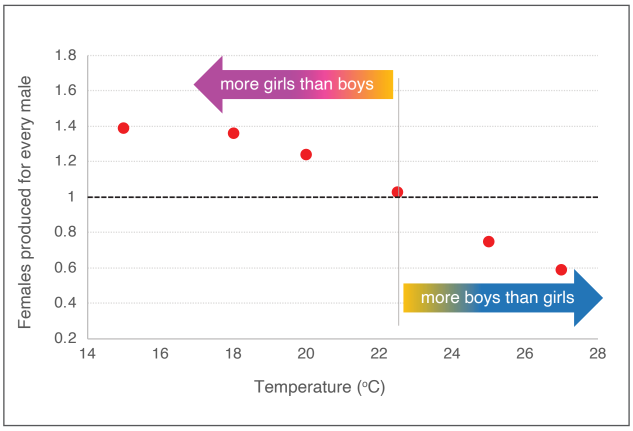

Figure 5. Temperature also affects the male to female sex ratio of phorids, with temperatures below 22°C increasing the number of female flies. Derived from Barzegar et al., 2016.

However, low temperatures also mean that adult flies live longer. For example, a female phorid will live for 4-5 days at 21°C, but 8-9 days at 15°C[6]. This increases her opportunity to mate and lay eggs.

Interestingly, temperature also has a big impact on the male to female ratio[4]. At low temperatures more females are produced than males. However, once the temperature goes over 22°C the situation is reversed, with more males than females (Figure 5).

Humidity is also important. Research indicates increasing RH from around 45% to 80% allows phorids to live at least 50% longer, with females being more responsive than males[5].

The cool (15 to 21°C), humid (>80%) conditions inside most mushroom grow rooms are therefore ideal for phorids. However, despite constant year-round conditions inside growing rooms, large seasonal fluctuations in populations occur. For example, in Pennsylvania fly populations double during spring, grow during summer, peak in autumn then dramatically decline during winter[7].

This is because the flies mate outside. Once the males emerge from their pupae, they leave the grow rooms and form groups outside, waiting for the females. A life-cycle study by Mazin et al[8] revealed that courtship and mating occur over grassy areas, with most activity from late afternoon until dusk. At these times great swarms ('leks') would form, with clouds of insects circulating rapidly close to the ground. Mating occurs mid-air, with around 30% of captured flies 'in-copula'.

Phorids were rarely found around spent mushroom compost or wooded, windbreak areas, further confirming that they only go outside to mate, then return to the grow rooms to lay eggs (Figure 6). Fresh compost, and piles of cooked-out spent compost, are not sources of infestation as they do not contain active *Agaricus* mycelium, so are therefore unattractive to the flies.

Agaricus mycelium can feed a lot of maggots; a single kilo of Phase III compost has been shown to support the development of 4,000 flies. Theoretically, this could translate into an apocalyptic 160,000 flies/m^2 inside a grow room, something nobody wants to experience!

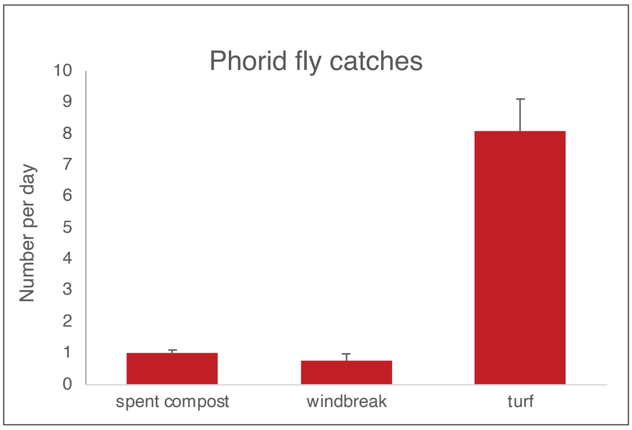

Figure 6. Number of phorids caught using yellow sticky traps placed at different locations around mushroom farms. Derived from Mazin et al., 2019.

6 Shikano I et al., 2021. Biology of mushroom phorid flies, Megaselia halterata (Diptera: Phoridae): Effects of temperature, humidity, crowding and compost stage. Environ. Entomol. 50:149-153.

7 Keil, CB., 2002. Mushroom integrated pest management. The Pennsylvania State University, PA.

8 Mazin M et al., 2018. Activity and distribution of the mushroom phorid fly, Megaselia halterata, in and around commercial mushroom farms. Entomol. Exp. Applicata. 167:389-395.

MANAGING PHORIDS

Chemical fly swats

The list of chemicals once registered in Europe to control phorids was long, including orghanophosphates, methoprene, benzoylurea, pyrethroids and carbamates. They were generally mixed into either the pasteurised compost or casing.

However, most can no longer be applied due to potential uptake of these chemicals into the mushrooms. Phorids first became a problem in Pennsylvania in 2012, when the US EPA cancelled the registration of diazinon insecticide for use on mushroom farms.

By the mid 1980s, *M. halterata* had become resistant to a wide range of insecticides[9]. Moreover, results were variable for several products, while others had toxic effects on the *Agaricus* mycelia[1].

There are several products registered for control of phorids on Australian mushroom farms. Most have fipronil as the active ingredient, while one has cyromazine. They are applied by mixing with peat during preparation of casing. There are no insecticides listed by APVMA which can be applied post-casing (N.B. Always use insecticides according to the label directions and confirm it is registered in your jurisdiction).

Biological fly swats

Biological products may or may not provide an alternative. For example, trials in Turkey[10] found that two neem-based products were as effective as chlorpyrifos at controlling phorid maggots in compost. However, the products were applied as a drench after casing, raising the possibility of transfer into the mushrooms. Although a natural plant extract, neem is not currently registered in Australia for use on edible crops, so approval of this use pattern seems unlikely.

Targeting the adult flies and avoiding contact with the mushroom substrate is a less problematic approach.

Pesticide screening by Penn State Researcher Dr Mike Wolfin showed that adult phorid flies were highly susceptible to a biopesticide composed of botanical oils (EcoVia EC by Rockwell Labs). The researchers applied the biopesticide to areas likely to be contacted by the flies, such as air vents and attic areas. It was also applied to electrostatic screens placed at key entry and exit points.

Dr Wolfin comments: "By November 2020 we were seeing almost complete elimination of phorids on our test farms. On the test farm where we implemented all the controls, we didn't find any flies."[11]

Another proposed control strategy lies with the white muscardine fungus *Beauveria bassiana*. This entomopathogenic fungus has a wide host range and can certainly kill insects.

A commercial formulation of *B. bassiana* (BotaniGard ES) has a label extension in the US allowing use in mushroom houses against phorid and sciarid flies (NB. this product is not currently registered with APVMA). Although Penn State researchers[12] found that exposure to the product led to 100% mortality of adult flies, it

Figure 7. Installing an electrostatic screen treated with biopesticide in a mushroom house, and dead phorids inside the screen.
- Photos: M Wolfin.

9 Cantelo WW. 1985. Control of Megaselia halterata, a phorid fly pest of commercial mushroom production, by insecticidal treatment of the compost or casing material. J. Entomol. Sci. 20:50-54.

10 Erler F. et al. 2008. Control of the mushroom phorid fly Megaselia halterata (Wood) with plant extracts. Pest Mgmnt. Sci. 65:144-149.

11 https://www.psu.edu/news/impact/story/penn-state-entomologists-devise-system-control-mushroom-phorid-flies/. Published online January 2021 by J Mulhollem.

12 Andreadis SS., et al. 2021. Efficacy of BotaniGard® against the mushroom phorid fly Megaselia halterata. Biocontrol Sci. Tech. 31:1098-1106.

Figure 8. The white muscardine fungus Beauveria bassiana is deadly against a wide range of insects, including this caterpillar.
- Photo by G Jacob.

Figure 9. Adult phorid fly. From Navarro et al., 2021.

took an average of eight days for flies to die. While a significant result, it was concluded that this was unlikely to meaningfully reduce phorid populations on mushroom farms.

Insect-attacking nematodes are another possible biological control agent. Various nematode species, include *Bradynema* spp. and *Howardula* spp. parasitise flies, and there are reports of infection rates reaching 60 to 75% during autumn when phorid populations are highest[13]. Unfortunately, while these nematode species can reduce egg laying, they do not kill their host. Rearing and releasing infected flies is therefore unlikely to provide a practical control measure[14].

There are also several *Steinernema* spp. nematodes that attack phorids. There have been positive reports of their effects when watered into the casing layer, not only on emergence of phorids but also on quality and yield of mushrooms [15]. Commercial formulations of factory grown nematodes are available in Europe and can be easily applied. Unfortunately, as with many biological products, effectiveness can be highly variable[1].

Avoiding the issue

Prevention is better than cure, so blocking access to growing mycelium is sure to be part of the answer. In the US, most farms load Phase II compost then conduct the spawn run inside the growing rooms. Once Phase III is complete, the rooms are opened to permit casing. Opening the room at this stage provides a powerful attractant to the invading phorids. One of the proposed control strategies is to avoid scheduling such critical activities at times when phorids are active. Phorids are inactive at night and cannot fly at temperatures below 15.5°C. Infestation of Phase III compost is therefore unlikely between sunset and early morning, and later in cooler areas.

Australian farms generally load Phase III compost, casing it as the room is filled. This presents a smaller window of opportunity to phorids, which may be one reason we have less problem with these pests.

Pennsylvania's cold winter breaks the phorid lifecycle, and this may also hold true in southern areas of Australia. It also seems possible that the hot, dry summer in parts of Australia could have a negative impact on the ability of phorids to lek and mate.

To conclude, a whole range of tools are available to help manage phorids. However, prevention is better than cure, so regular scouting and monitoring is the first step to managing these tiny pests.

13 Hussey, NM. 1964. Observations on the association between Bradynema sp. (Nematoda : Allantonematodidae) and the mushroom infesting fly Megaselia halterata (Diptera:Phoridae). In "Proc. 12th Int. Conf. Entomol." London, UK:pp. 71-83.

14 Richardson PN, Chanter DO. 1981. Aspects of the laboratory production of mushroom phorid flies (Megaselia halterata) parasitised by the nematode Howardula husseyi. Ann. Appl. Biol. 99:1-9.

15 Grewel PS, Richardson PN, Collins G, Edmondson RN. 1992. Comparative effects of Steinernema feltiae (Nematoda: Steinernematidae) and insecticides on yield and cropping of the mushroom Agaricus bisporus. Ann. Appl. Biol. 121:511-520.