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# Mushroom fly pest incidence in four button mushroom (*Agaricus bisporus*) production centres of Zimbabwe-An exploratory study

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**ABSTRACT**

Mushroom fly pests are a serious deterrent to many wood-be button mushroom producers in Zimbabwe due to their yield and quality degrading damage. Mushroom fly ubiquity is exacerbated by conducive environmental factors, arguably the rampant food and fruit waste disposal in the environment. Although modest fly pest management methods are available, expensive methods are employed to contain pest spread and the subsequent damage they cause. The aim of this exploratory study was to investigate prevalence, infestation sources, damage, seasonal severity and control methods for mushroom fly pests on button mushroom farms in four production centres of the crop. A farmer survey was conducted using a postal questionnaire to farmer respondents using a mobile phone-integrated application. This study found that sciarid and phorid fly attack button mushroom crop starting at the early spawn running phase through to the second crop flush with rapid population build up if uncontrolled. The infestations were found to be high across four surveyed sites with greatest infestations coinciding with the rainy season. Mushroom fly incidence and the damage to button mushroom were not explained by location or farmer experience, making these two variables insignificant in constructing a predictive model for the resultant fly pest incidence or crop losses experienced. Hence production practices need to be re-evaluated to develop sustainable methods of managing mushroom fly incidence and novel methods such as fly repellents, baiting or manipulation of the mating mechanisms and overwintering disruption have to be explored. From this study we found three species of mushroom fly as significant button mushroom pests in the studied areas and hence appropriate pest management measures must be taken to protect the crop to enable good quality and yield. Such adopted pest management methods will go a long way in promoting and sustaining standard agro-ecological principles.

***Keywords*:** mushroom fly, incidence, crop damage, spawn running, pinning, Agaricus bisporus, pest management

## Introduction

White button mushroom cultivation began earnestly in the 1990s in Zimbabwe. Since then, the area and seasonal space under the crop has grown as demand continues to rise, complementing its oyster mushroom counterpart on the urban and catering industry market and a variety of wild mushrooms mainly consumed in rural markets (Mlambo & Maphosa, 2022; Chitamba et al., 2012). Button mushroom has helped in satisfying specialty markets in hotels, restaurants, and hospitals and among tourists from mycophillic cultures elsewhere such as continental Europe, China and Japan (Peintner et al., 2013). Although white button mushroom growers worldwide have significantly contributed to global food security, in Zimbabwe the bulk of this sector remains largely constrained by pest affliction (Navarro, 2020). Quite a few pests have been reported through oral and undocumented discourses. Hence it has until now remained unclear what pests are of significant economic importance as experienced by button mushroom growers in Zimbabwe. This paucity of knowledge has been exacerbated by a presumed culture of secrecy in developments within the mushroom farming sector of Zimbabwe, which is relatively unregulated by the state. Thus, for Zimbabwe, the real significance of pest problems in white button mushroom production has not received any significant research attention.

World-wide, several button mushroom pests, the majority being insects, have been studied extensively with corresponding pest management methods developed (Lee et al., 2022; Shamshad, 2010; Sharma et al., 2021). Topping the groups of button mushroom pests are members of Diptera order, mites, springtails and a variety of beetles (Kakraliya, 2022). Among these pests, the most frequently encountered are sciarid flies (Diptera: Sciaridae) *viz*. *Lycoriella ingenua*, *L. auripila*, *L. agarici*, *Sciara multiselta*, *S. agaris*, *Bradysia paupera*, *B. tritici*, and *S. orientalis*; Cecid flies (Diptera: Cecidomyiidae) including *Mycophila speyeri*, *M. borresi*, *Heteropeza pygmaea* and phorid fly (Diptera: Phoridae): *Megaselia nigra*, *M. sandhui*, *M. halterata*, and Springtails (*Seira iricolor*), mites eg. *Microdispus lambi*, beetles e.g. *Cyllodes indicus*, *Scaphisoma nigrofasciatum*, *Staphylinus* sp. and *Spondotriplax pallidipes* (Lee et al., 2022; Kumar et al., 2022; Coles et al., 2021; Sharma et al., 2021; Kakraliya & Kumawat, 2022; Navarro, 2020; Sharma et al., 2019). The sciarid fly, *Lycoriella*, is by far the most serious and most ecologically widespread arthropod pest of button mushroom worldwide (Lee et al., 2016; Andreadis et al., 2016; Marques et al., 2021). The most reported damage experienced on button mushrooms is by the phorid fly *Megaselia halterata* in Spain, leading to 10 to 40% yield loss if uncontrolled (Navarro, 2020) while in India sciarids, cecids and phorids are reported to have caused 17-26%, 26-33% and 46% yield loss respectively when uncontrolled (Limbule et al., 2021). Furthermore, *Lycoriella ingenua* is known to vector green mold (*Trichoderma aggressivum*) spores, mushroom mites and nematodes (Lee et al., 2022; Coles et al., 2021; Limbule et al., 2021) and also transmits the mushroom pathogenic fungus *Trichoderma aggressivum* Samuels & W Gams (Mazin et al., 2017) while its larvae feed on and destroy both the mushroom mycelium and the compost (Shamshad,2010). Apart from the shortened life cycle of around 20 days and their capacity to oviposit large numbers of eggs, some cecid species have been reported to be paedogenetic, hence their enhanced fungivory fitness (Rijal et al., 2021; Jaiswal & Kumar, 2020). To mitigate potential damage, the most effective control methods developed to date rely on hygiene as the first line of defence, quarantine of affected crops and chemical control often used sparingly on commercial farms as backup counter-pest measures (Gill and Allan, Accessed 7 July 2025).

Use of chemical pesticides such as paralyzing pyrethroids, growth regulating cyromazine, and botanicals, neem oil and horticultural oil in mushroom production, has also been reported (Navarro et al., 2021). Other chemicals used against mushroom fly in general are: benomyl, parathion, malathion, beta-cypermethrin, diflubenzuron, and pyriproxyfen (Nair et al., 2023). Analysis of 49 fresh and dried mushroom samples reaching markets in the Czech Republic from several countries found 21 residues of different agro−pesticides (Schusterova et al., 2023). It is, however, unclear whether such chemicals had been directly used on the mushroom crops or were bio−accumulated by the mushrooms from their growing substrates. It is strongly cautioned, however, that use of these or any other alternative synthetic chemical pesticides in mushroom production should be discouraged, particularly in mushroom production and marketing systems not well regulated such as those of Zimbabwe. It however has remained unclear which strategies are in use by Zimbabwean button mushroom growers.

The short life cycles for most button mushroom pests and prevalence of several alternative hosts such as wild mushroom species and rotting organic debris makes it difficult to control mushroom pests (Navarro et al., 2021). However, in Zimbabwe, the first step in identifying and appreciating the pest range and biology is still in its infancy. The most frequently and most damaging pests have not been determined and may vary by geographical region, thereby necessitating this survey. Elsewhere outside Zimbabwe, several fly pests within the three taxonomic families have been found and specific control measures developed for the examples in **Table 1**.

**Table 1.** Most frequently and most damaging mushroom pests and control measures employed

| Pest | Alternative hosts | Damage caused | Nonchemical control methods | References |
|---|---|---|---|---|
| Sciarid fly [Sciaridae:*Lycoriella* sp., *Bradysia* sp.] (dark−winged fungus gnats) | Wild mushrooms, plant roots, algae, rust and smut fungi, decaying plant debris, lichens, ferns | Eat [ǃ]**MM** mycelium and compost, larvae tunnel stipes, discolouration of caps, transmit fungal, viral and bacterial contaminants | ***Bb***; [†]**PM+Ma; light traps,** sticky or pheromone or yellow traps, physical barriers, temperature control between 16 and 18°C, parasitoid wasps, repellent plants like mint or basil | Andreadis et al. (2021); Tavoosi Ajvad et al. (2019); Nair et al. (2023); Rijal et al. (2021); Anderson et al. (2021) |
| Phorid fly [Phoridae: *Megaselia* sp.] (humpbacked/scuttle fly) | Wild mushrooms, dead arthropods, decaying flesh, rust and smuts | Feed on mushroom mycelium, transmit *Verticillium* contaminant, bacteria and viruses | ***Bb**; eclosion, juvenile hormone analogues, attractant volatile laced traps, **EPNs**; **Bt**; **PM**; plant extracts, parasitoid wasp, physical barriers | Andreadis et al. (2021);Navarro et al. (2021); Jaiswal & Kumar (2020) |
| Cecid fly [Cecidomyiidae: *Mycophila* sp. *Heteropeza* sp.] (gall midge) | Wild mushrooms, plant aerial and subterranean parts, rusts, smuts, ferns, mosses, bacteria, algae, | Feed on mycelium; gall on sporophores; sporophore deformation and discolouration; size reduction; vector mites, nematodes. disease | Parasitoids, physical barriers, traps, horticultural oil | Jaiswal & Kumar (2020); Rijal et al. (2021) |

[ǃ]Mushroom mycelium (**MM**);*eg BotaniGard® with *Beauveria bassiana* (***Bb***);[†]*Metarhizium anisopliae* (Hypocreales: Clavicipitaceae) Metchnikoff (Sorokin) plus **P**redatory **M**ites *Gaeolaelaps aculeifer* (Canestrini) (Mesostigmata: Laelapidae) syn. *Hypoaspis aculeifer* Beaulieu (**PM+Ma**); entomopathogenic nematodes (**EPNs**); *Bacillus thuringiensis* (**Bt**);

The general characteristic anatomical features and conditions conducive for development of mushroom fly pest infestations on button mushrooms vary in production areas with many factors including the nature of the production system and prevalence of alternative hosts in the production area.

In white button production areas where there is a short mushroom growing tradition or little local research knowledge such as Zimbabwe, yield loss is largely attributed to mushroom fly. Through this button mushroom grower survey, the objectives set were to determine: 1) the type of white button mushroom Dipteran pests encountered and the perceived damage they cause, 2) the comparative frequencies of pest incidence for each location and for each cropping stage up to the second flush, 3) mathematical model for incidence of each Dipteran pest for four production stages, *viz*. spawn running, pinning, capping and second flush as predicted by farmer location and farmer experience, 4) the difference in percent yield losses across three recognized seasons of production and among the locations studied, 5) the presumed sources of mushroom fly infestations and 6) the pest management methods in use. Hence the role such pests play in white button mushroom production in Zimbabwe can be better understood from findings of this research.

## Materials and methods

### Study site

The farmer survey was conducted across four major population and button mushroom production centers of Zimbabwe: Harare, Gweru, Masvingo and Bulawayo as an exploratory survey. The snowballing technique, where the spawn supplier identified the population of grower respondents (spawn purchasers/customers) was used (Moxley et al., 2022; Mutema et al., 2019). This snowballing technique was the most effective approach owing to the latency of button mushroom growers in Zimbabwe linked to the unregulated nature of this sector.

### Survey research design, instrument and sample size

A descriptive survey was conducted among white button mushroom farmers of Zimbabwe to determine the pest inventory observed on their crops, the nature of damage they caused and control strategies they employed. Semi structured questionnaires were conducted from a population of 480 growers of white button mushroom distributed unevenly throughout the country and with noted categories of button mushroom growing experience of less than two years, two to five years or more than five years. All questionnaires were administered through the android assisted Kobo Collect application on the WhatsApp platform to cover a sample of 62 respondents selected in a location population proportionate stratified sampling manner. This sample size covered 15% of the total number of button mushroom growers in Zimbabwe with 100% questionnaire return rate.

### Data collection

From each respondent, data were gathered on: grower location; button mushroom growing experience in years; Dipteran pests encountered by grower by season and production phase of the crop; suspected or proved sources of infestation; suspected or proved alternative pest hosts; ranking of pest severity by growing season; symptoms of crop damage; percent yield loss where applicable by season, and methods used to manage the Dipteran pests and estimated effectiveness of such methods. Responses from the survey were collated in tabular data capture form in MS Excel as questionnaires were returned. The data were coded, cleaned, validated and required computations made before analysis. The survey captured data in in the following main categories: Location, experience, symptoms of damage by mushroom fly, mushroom fly pests encountered, suspected sources of infestation, severity of damage by season (0 to 10% or > 10% yield loss) and methods used to manage/control infestations.

**Data analyses**

All analyses were conducted in SPSS 20.0 (IBM, 2011). Data from surveys was computed and bar-graphed in order to visualize frequency trends for the major pests using MS Excel. For all statistical analyses data from the four major button mushroom production centers, *viz*. Harare, Gweru, Masvingo and Bulawayo were converted into response frequencies by data category and visualized using bar charts generated in MS Excel. Binary logistic models for incidence of each of sciarid, phorid and cecid flies as predicted by farmer location and farmer experience were developed for each of four cropping phases *viz*. spawn running, pinning, capping and flush 2 to test the regression model:

$$\log(p/[1-p]) = \boldsymbol{\beta 0} + \boldsymbol{\beta 1}\text{Farmer Experience} + \boldsymbol{\beta 2}\text{Location}$$

Where $p$ = probability of pest incidence, $\boldsymbol{\beta 0}$ is the intercept, $\boldsymbol{\beta 1}$ and $\boldsymbol{\beta 2}$ are coefficients

To compare yield loss rankings (low= 0 to 10%; high= > 10%) among three production seasons (September to February, March to May and June to August), a Kruskal Wallis test was used. We also used the Kruskal Wallis test to compare yield loss differences across the four study locations. For statistical analyses conducted, tests of data normality (Shapiro-Wilk) and homogeneity of variance (Bartlett's test) were conducted and descriptive tests done in SPSS.

**Results**

This study determined Dipteran pest prevalence in Zimbabwe's four major button mushroom production areas, that is, Harare, Gweru, Masvingo and Bulawayo municipal districts. Symptoms of damage, mushroom fly pests involved, crop stages affected, sources of infestation and management measures taken were also determined. Predictive models for pest prevalence as a function of location and farmer experience were then tested to help further explain the data.

**Dipteran pests observed and production stages infested**

All respondents (100%) were found to experience incidence of three mushroom fly pests, namely, sciarid, phorid and cecid fly to varying degrees at some point in their enterprises annually. The exact species of each group were not characterized as this was beyond the scope of the current study. Stem tunneling was the most frequently reported symptom of damage and most farmers appreciated other additional symptoms of damage (**Figure 1**).

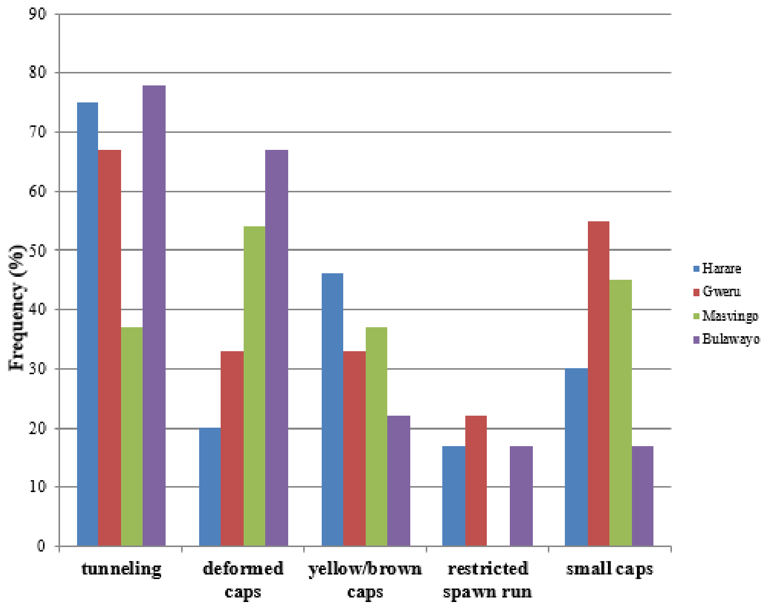


**Figure 1.** Reported symptoms of damage by mushroom fly pests

The three groups of mushroom pests were found in the four districts as shown in Table 2. Of particular note are the sciarid and phorid flies reported to infest all production stages while cecids were only observed at the two initial stages.

**Table 2.** Range of pests encountered in button mushroom and stages of production where observed

| Pest | Order | Production phase |
|---|---|---|
| Sciarid fly | Diptera | All phases |
| Phorid fly | Diptera | All phases |
| Cecid fly | Diptera | Spawn running and pinning |

**Incidence of mushroom fly infestation for the various production stages/phases**

The affirmative response frequencies for mushroom fly incidence across the four sites were found to vary throughout the cropping cycle from spawn running to the second flush (**Figure 2**). Peak infestation was found at pinning phase of the first crop while the lowest infestation frequency was at spawn running phase. For all production locations mushroom fly incidence was similar between the capping phases 1 and 2. Across all locations the sciarid fly (=fungus gnat) was affirmatively mentioned most frequently of the three mushroom flies while the cecid fly appeared least mentioned. Hence, both the sciarid and phorid fly pests appeared to be serious pests while cecids were relatively less important.

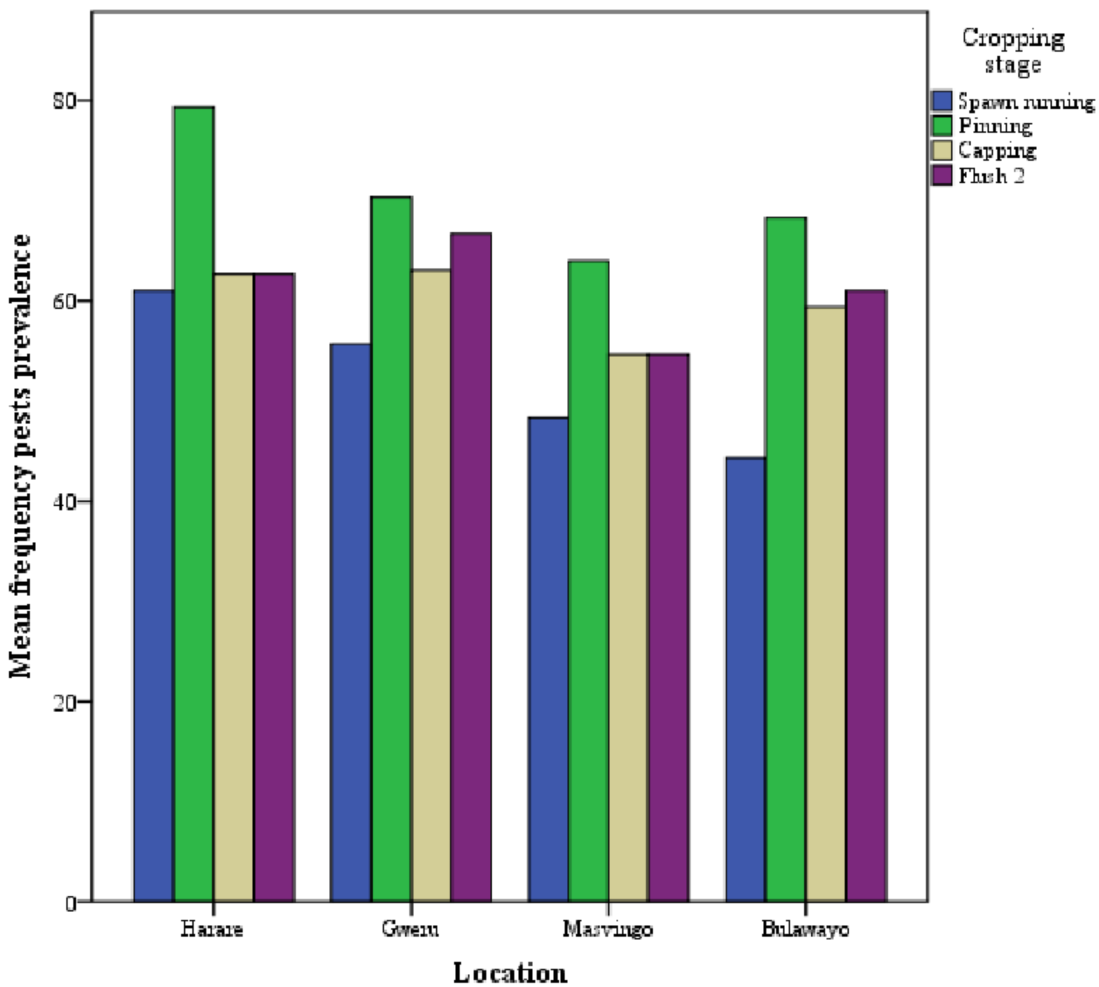


**Figure 2.** Individual fly incidence frequency across the four production centers

**Frequency trends of incidence for the three mushroom flies across the production phases**

Sciarid fly affirmative mention frequency was highest at the first capping phase and lowest at the spawn running phase. In contrast, phorid fly mention frequency was highest in the second flush. Cecids appeared to be prevalent only during spawn running and pinning and vanished thereafter (**Figure 3** and **Figure 4**).

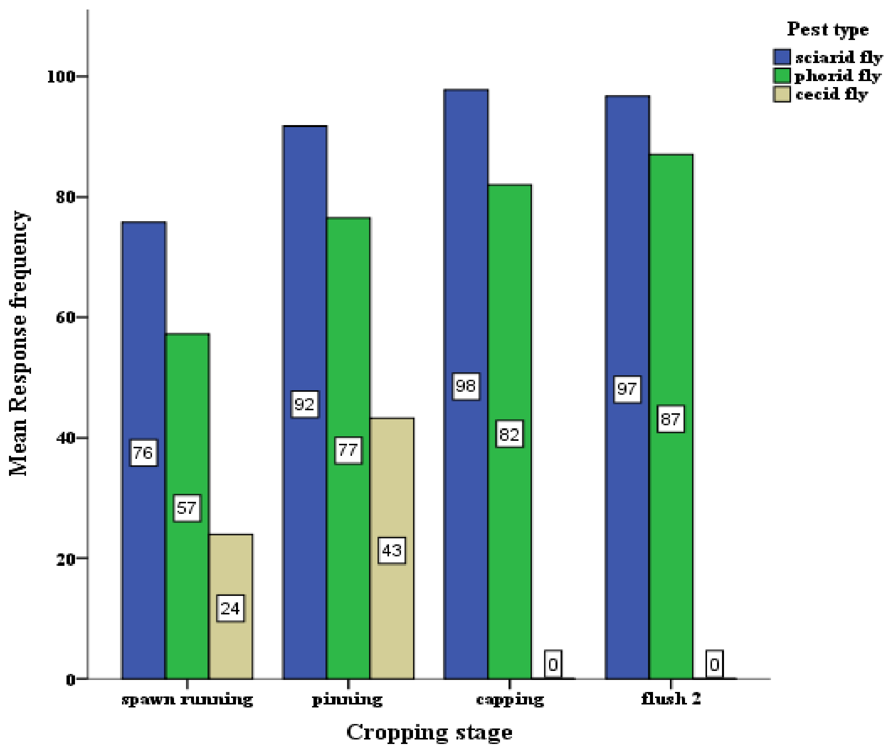


**Figure 3.** Mushroom fly incidence frequencies for the four stages of cropping

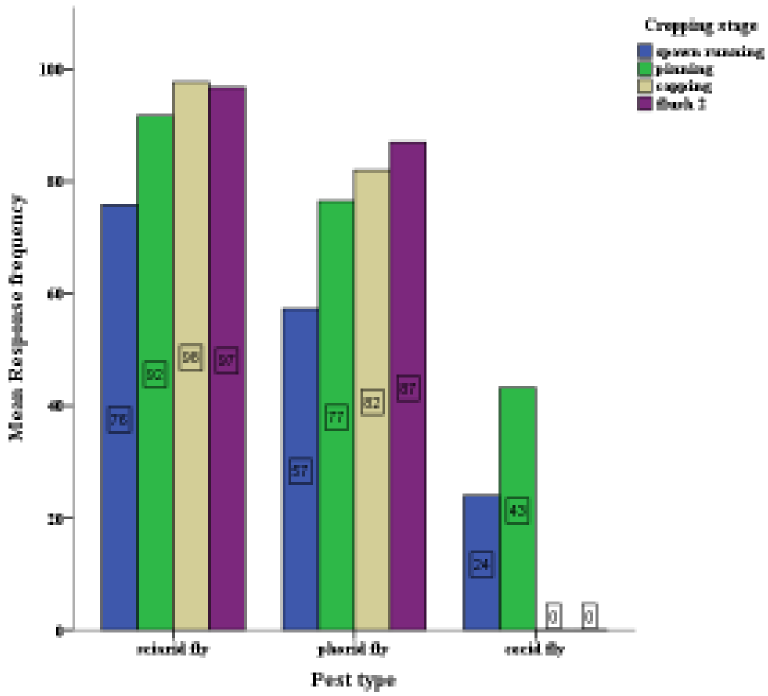


**Figure 4.** Frequency of pest incidence across the four production stages

## Predictive models for pest incidence

Farmer location and farmer experience were regressed on incidence frequency for each mushroom fly pest type and for the mushroom production phases: spawn running, pinning, capping (first flush) and second flush. We ran binary logistic regression in SPSS 20.0 to test our data on the model:

$$\log(p/[1-p]) = \boldsymbol{\beta 0} + \boldsymbol{\beta 1}\text{FarmerExperience} + \boldsymbol{\beta 2}\text{Location}$$

Since cecid fly incidence was not observed and hence not reported neither at capping nor flush 2 across all farmer locations, these analyses were not run.

### Regression of farmer experience and location on probability of pest incidence at spawn running

Although the constant was significant ($p < 0.05$) neither of the predictors (farmer experience and farmer location) were significant ($p > 0.05$). For the incidence of sciarid, phorid and cecid fly incidence both the Cox & Snell and Nagelkerke R square were less than 25% (**Table 3**), indicating that each of the model accounted for less than 25% of the total variance, hence farmer experience and location do not explain incidence of these pests. This model was therefore not significant for any of the three pests.

**Table 3.** Binary logistic regression for pest incidence at spawn running phase as predicted by location and farmer experience

| | Sciarid fly | Phorid fly | Cecid fly |
|---|---|---|---|
| **Hosmer–Lemenshow value** | P=0.902 | P=0.946 | P=0. 581 |
| **–2 Log Likelihood value** | 66.945 | 77.975 | 65.366 |
| **Cox & Snell R Square** | 0.060 | 0.106 | 0.140 |
| **Nagelkerke R square** | 0.089 | 0.142 | 0.200 |
| **N** | 62 | 62 | 62 |
| **Constant** | P<0.001 | P=0.311 | P=0.001 |

**Regression of farmer experience and location on probability of pest incidence at pinning**

We found a significant (*p*< 0.001) constant but neither farmer experience nor location was significant (*p*> 0.05) with a not so low Nagelkerke R-square value of 22.1% for sciarid fly (**Table 4**). Overall, the R-squared value was also below 25% for any of the three pests for the pinning stage and hence, not significant.

**Table 4.** Binary logistic regression for pest incidence at pinning phase as predicted by location and farmer experience

| | Sciarid fly | Phorid fly | Cecid fly |
|---|---|---|---|
| **Hosmer–Lemenshow value** | P=0.782 | P=0.720 | P=0. 957 |
| **–2 Log Likelihood value** | 32.626 | 56. 646 | 81.140 |
| **Cox & Snell R Square** | 0.104 | 0.107 | 0.059 |
| **Nagelkerke R square** | 0.221 | 0.167 | 0.079 |
| **N** | 62 | 62 | 62 |
| **Constant** | P<0.001 | P<0.001 | P=0.311 |

**Regression of farmer experience and location on probability of pest incidence at capping stage**

The constant was significant (*p*< 0.001) for both sciarid and phorid fly incidence though with low Nagelkerke R-square value for both pests (**Table 5**). Our model was also not significant for both pests for the capping stage.

**Table 5.** Binary logistic regression for pest incidence at capping phase as predicted by location and farmer experience

| | Sciarid fly | Phorid fly | Cecid fly |
|---|---|---|---|
| **Hosmer–Lemenshow value** | P=0.771 | P=0.134 | − |
| **–2 Log Likelihood value** | 16. 946 | 45.230 | − |
| **Cox & Snell R Square** | 0.012 | 0.039 | − |
| **Nagelkerke R square** | 0.047 | 0.072 | − |
| **N** | 62 | 62 | 62 |
| **Constant** | P<0.001 | P<0.001 | − |

**Regression of farmer experience and location on probability of pest incidence at flush 2 stage**

The constant was significant ($p< 0.001$) for both sciarid and phorid fly incidence but with low Nagelkerke R-square for both pests (**Table 6**). Our model was also not significant for both pests for the flush 2 stage.

**Table 6.** Binary logistic regression results for pest incidence at flush 2 as predicted by location and farmer experience

| | Sciarid fly | Phorid fly | Cecid fly |
|---|---|---|---|
| **Hosmer–Lemenshow value** | P=0.771 | P=0.134 | − |
| **–2 Log Likelihood value** | 16.946 | 45.230 | − |
| **Cox & Snell R Square** | 0.012 | 0.039 | − |
| **Nagelkerke R square** | 0.047 | 0.072 | − |
| **N** | 62 | 62 | 62 |
| **Constant** | P<0.001 | P<0.001 | − |

**Nature of damage and yield loss versus production season**

Farmers were aware of the symptoms of fly damage *viz*. tunneling of sporophores, deformed caps, yellowing/browning caps, restricted spawn run and small size sporophores. They appreciated that any form of damage directly led to yield loss and that off−quality produce was not marketable. Using the Spearman Correlation test, we found a significant ($p< 0.001$) moderate negative correlation ($r$ = –0.290; n = 186) between yield loss magnitude and production season (from summer–winter–spring). We used the Kruskal−Wallis test in SPSS 20.0 to test the difference in the reported button mushroom yield losses among the three production seasons (for all production locations). More yield loss was experienced in summer than winter and more in winter than spring (**Table 7**). There was no significant ($p< 0.05$) difference in reported yield loss from mushroom fly among the study locations.

**Table 7.** Kruskal–Wallis mean rankings of button mushroom yield loss in three production seasons

| Statistic | Value |
|---|---|
| **Season** | Mean rank (yield loss) |
| **September to February** | 108.00 |
| **March to May** | 97. 50 |
| **June to August** | 75.00 |
| **Chi–square value** | 16.221 |
| **df** | 2 |
| **p** | $< 0.001$ |

**Presumed sources of mushroom fly infestations**

Four sources of mushroom fly infestations were succinctly mentioned as compost, spawn, nearby fruit trees and the unhygienic, overly humid environment while a sizeable number of respondents appeared not to know the sources (**Figure 5**).

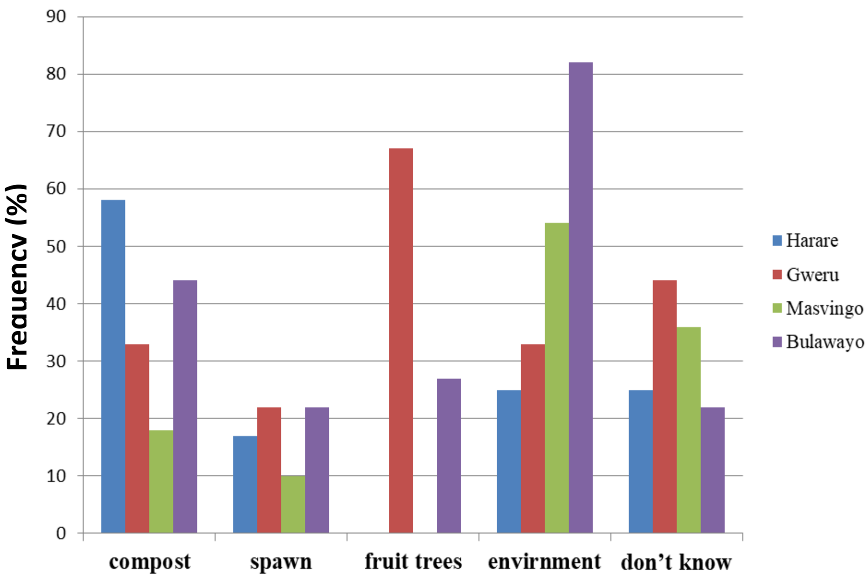


**Figure 5.** Respondent frequencies for mention of the presumed sources of infestation

**Management methods for mushroom fly**

Across the surveyed locations, button mushroom farmers reported use of thorough compost sterilization, plugging of all entry points for mushroom fly into the mushroom house. They also remove fly sources such as vegetation, waste food dumps. Diazinon pesticide sprays were administered inside the mushroom house to control fly infestations.

**Discussion**

This study showed that mushroom fly (both sciarid and phorid groups) were the most important pest of button mushroom in the major production locations of Zimbabwe. This finding is similar to studies elsewhere in India (Kakraliya, 2022); in Korea (Lee et al., 2016); the United Kingdom and the US (Navarro et al., 2021). Like reports by Navarro et al. (2021); Navarro et al. (2020) and Babytskiy et al. (2019), we also found higher incidence for sciarid than phorid fly incidence (**Figures 2−4**). Chidziya et al. (2013) reported the sciarid *Lycoriella mali* as the most damaging in Zimbabwe, which is consistent with our findings. Throughout this survey, farmers appeared to be aware of the identities of three distinct groups of mushroom fly, *viz*. sciarids, phorids and cecids. However, a few farmers could not assign the observed fly pests to their taxonomic species but were able to describe their structure and behavior. This indicates a critical knowledge gap for which correct prescription of effective fly management methods could be resolved. Our findings demonstrated that mushroom fly; in particular, sciarid and phorid groups were location and season ubiquitous on button mushroom farms in this study. However, yield losses peaked in summer contrary to reports by Navarro et al (2021; 2024) where phorid fly infestations, in particular, peaked in spring and autumn in temperate climates. The high value placed on button mushroom quality makes it imperative for farmers to swiftly trace the damage to fly infestations experienced. Hence farmers promptly seek expert advice from mushroom consultants and entomologists to identify the pests and recommend control measures. We also observed that farmers frequently share knowledge through the WhatsApp platform groups such as the one we used in collecting data for this study. With the advent of the Internet global information and artificial intelligence tools, farmers are also able to search for solutions using their smart phones for the bare basics such as the difference between the three groups of mushroom fly. Since the main incentive for venturing into button mushroom production is profit making prospects, most farmers do not necessarily have formal training in entomology, nor do they employ an entomologist owing to the small scale of production which constrains hiring of such specialists.

The ubiquity of mushroom fly we found is consistent with prevailing conditions of cool to warm temperatures, high humidity and dark conditions maintained inside button mushroom houses irrespective of seasonality and geographical location (Navarro et al., 2020). Typically, for spawn running internal temperatures are maintained between 19 and 24°C and humidity ca. 85% under pitch dark conditions coinciding with the optimum conditions favoring successful completion of all stages of mushroom fly life cycle. Under such conditions, therefore, it is very likely that the damaging fly larvae observed during spawn running arise from early infestation of the compost when eggs are laid at or just after spawning rather than before spawning infestation. A study by Kakraliya (2022) and Rijal et al. (2021) found similar infestation patterns in India where fly maggots was highest towards end of spawn running, also implying highest adult incidence at pinning. Hence, the early spawn running phase appears the strongest stimulus for sciarid and phorid fly oviposition compared to subsequent stages. Within seven days, eggs hatch into larvae which start feeding on the still sparse mushroom mycelium thereby slowing spawn running. After completing the life cycle, a new and larger wave of infestation begins if uncontrolled. In particular, sciarid fly is known to complete its life cycle in 25 days at 21°C (Chidziya et al., 2013) which represents the first wave of adults found in the mushroom house. It is therefore critical that early exclusion of the fly be effected to arrest early infestations, particularly in the warm season when adults can freely mate to allow for good pinning and the subsequent capping.

The higher frequencies of sciarid and phorid fly incidence in Harare and Gweru than the other two locations (**Figure 2**) is explained by higher humidity experienced in these areas, indicating that there is a higher likelihood of reserve fly populations in humid areas, with abundant wild mushrooms and decaying litter being the most likely alternative hosts in the summer. In drier areas of Masvingo and Bulawayo the longer drier winters tend to suppress reserve populations thereby allowing a lower pest incidence in the following summer crop. On the other hand, cecids appear to be a minor challenge throughout the four areas. This is attributed to cecids preference for fresh plant material rather than fungal mycelium. Hence the rare encounter with cecids makes them insignificant as button mushroom pests within the studied areas, being just a transient pest where their primary plant hosts are unavailable.

As expected, the populations of sciarid and phorid fly larvae and adults increase after spawning and peak off at capping (Navarro et al., 2021). This phenomenon is demonstrated by the trends in their incidence (**Figure 3**) indicating that farmers generally establish their button mushroom crop with relatively uninfested compost. Whether initial infestations of the compost arise from the compost itself or the environment, pest numbers increase on the growing mycelium as their primary food and the subsequent fruit body primordia at end of spawn running. Hence the large number of emerged adult flies at the first capping stage. It is at this stage that farmers apply and intensify chemical control measures which tend to suppress resurgence of pest populations possibly leaving the residual pupa population unharmed. Furthermore, the leveling off in the infestation at capping, more clearly shown in **Figure 4** is because sporophores are less favorable as forage than fresh compost and fungal mycelium. Although our survey focused on pest incidence frequency rather than actual pest population numbers, higher population numbers of sciarid than phorid were explained on the higher trophic and reproductive fitness of the former than the latter. Whereas sciarids can oviposit on unspawned compost phorids do not. Adult sciarids start oviposition within six hours after eclosion whereas phorids oviposit three days after eclosion (Jaiswal and Kumar. 2020). This difference in oviposition fitness may be extrapolated, albeit with caution, to explain the higher frequency of sciarid than phorid incidence and population dynamics in all cases.

Farmer location and experience proved poor predictors of mushroom fly incidence in general, only being able to explain less than 25% of the variation. However, the significant ($p < 0.001$) constant we found in all cases indicates that indeed, there are other factors than farmer location or experience which could be explored. A nonlinear more robust model accounting for factors other than those we considered may be required for practical application on mushroom farms. We however, did not collect pertinent data on parameters such as composting methods used, fly species or exact growing conditions which might be better predictors for fly pest incidence. Data on the pest management practices used by different farmers to resolve the challenge of pest incidence were also not collected. In Zimbabwe there is currently little data on mushroom fly species identity and diversity or distribution in relation to mushroom production.

Farmers clearly identified some of the visible damage directly arising from mushroom fly. They appreciated the quality loss as this also directly impacted on marketability of their produce, giving them incentive to manage mushroom fly infestations. Stem tunneling and cap browning we found as caused by fly larvae was also reported elsewhere in India by Ruchika et al. (2024) as a major quality loss for button mushrooms. However, they were unable to relate the subterranean effects of the fly larvae damage on mycelium and the compost. None of the respondents mentioned observation of pupae, which usually are visible on the surface of the substrate starting in the second and third week after spawning, an indicator which could guide timing of chemical control. The difference in yield losses (**Table 7**) attributed to mushroom fly among the seasons is directly linked with the differences in infestation rates experienced in the seasons. The summer months are characterized by highest mushroom fly activity when outdoor temperatures are highest and thus most suitable for mating of flies just outside the mushroom houses (Navarro et al., 2021; Limbule et al., 2021).

Temperature, relative humidity and, hence, litter decomposition in the surrounding galleries and woodlands are also suitable for breeding large populations of fly constituting sources of infestation. On the contrary, as outdoor temperatures and humidity fall, external sources of infestation also diminish leading to less yield losses into the cold dry winter. Generally, farmers appeared to trust their spawning material as free from pest infestation (**Figure 5**). The major sources of pest infestations were believed to be the compost when not properly pasteurized and the environment such as rotting litter and refuse dumps. Less likely sources were the general environment, that is, fly pests were perceived as endemic, with fruit trees being suspected to harbor reserve pest populations. All these suspicions seem plausible as mushroom flies are known to be generalists, capable of feeding on a wide range of decomposing materials. Hence, continued removal of refuse dumps, removal of suspected breeding and overwintering habitats such as fruit trees, food waste containers, and proper sterilization of composts continue to remain viable chosen methods. However, for such methods, proper planning and sequencing is required while more environment-friendly methods need to be developed.

## Conclusion and future perspectives

This study found that sciarid, phorid and cecid mushroom fly species were the prevalent pests of button mushroom across Harare, Bulawayo, Gweru, Mutare and Masvingo production areas. These pests cause yield and quality losses throughout the production seasons, particularly in the summer months. They were reported to feed on the compost, tunnel mushroom stems and causing mushroom browning leading to unmarketable produce. No association was found between study location or farmer experience and prevalence on the mushroom farms. The major sources of infestation reported were the immediate environment and poorly pastuerised compost. Hence respondents using effective compost sterilization techniques and maintaining hygienic environments as the most viable pest management approaches. Although the sciarid fly was reported as the most important fly pest the damage caused by individual pest genus was not determinable as the infestation cycles of the three pest groups tend to overlap across crop production phases and flushes. Hence robust mushroom fly management methods are essential in attempting to reduce this threat, particularly during wet warmer months of the year. With little mushroom pest research published so far focusing on button mushroom pests, more research needs to be done towards accurately characterizing the mushroom fly pest complex in Zimbabwe and develop safe, affordable, effective and sustainable methods to manage them. Hence this contribution challenges research institutions to channel resources towards developing local methods of managing mushroom fly in Zimbabwe. While these findings provide significant insights into the prevalence of mushroom fly pests in the areas of study, it is essential to interpret them with caution due to the exploratory nature of this study, which may limit the generalizability of the results.

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