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The flies on mushrooms cultivated in the Antalya-Korkuteli district and their control

Antalya-Korkuteli Yöresi'nde kültürü yapılan mantarlarda bulunan sinekler ve mücadelesi

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ABSTRACT

Over the last two decades, mushroom growing has become one of the most dynamically developing fields of agriculture in Turkey. In parallel with this development, populations of some arthropod pests, especially mushroom flies belonging to different families of the order Diptera, have steeply increased in recent years. Sciarid, phorid and cecidomyiid flies, especially *Lycoriella ingenua* (Dufour) (Sciaridae) and *Megaselia halterata* (Wood) (Phoridae) being the most common species in the Antalya-Korkuteli district (South-Western Turkey), affected the cultivation of white button mushroom [*Agaricus bisporus* (Lange) Imbach], the most commonly grown mushroom species in Turkey. Recently, mushroom scatopsid flies (Scatopsidae) have arisen as a serious new threat in the Antalya-Korkuteli district. It is surmised that the infestation by these flies has affected approximately 70% of the mushroom growing cellars in the district. Until now, a total of 15 fly species (Sciaridae: 3, Phoridae: 1, Cecidomyiidae: 8 and Scatopsidae: 3) was detected to cause damage in the cultivated mushrooms in the Korkuteli district.

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ÖZ

Son 20 yıldır, mantar yetiştiriciliği Türkiye'de tarımın en hızlı gelişen alanlarından biri olmuştur. Bu gelişmeye paralel olarak, bazı arthropod zararlıların, özellikle Diptera takımının farklı familyalarına ait mantar sineklerinin, popülasyonları son yıllarda hızla artmıştır. Sciarid, phorid ve cecidomyiid sinekler, özellikle Antalya-Korkuteli Yöresi (Güney-Batı Türkiye)'nde oldukça yaygın olan *Lycoriella ingenua* (Dufour) (Sciaridae) ve *Megaselia halterata* (Wood) (Phoridae) Türkiye'de en çok üretilen mantar türlerinden Beyaz şapkalı mantar [*Agaricus bisporus* (Lange) Imbach]'ın kültürünü etkilemektedir. Son zamanlarda mantar scatopsid sinekleri (Scatopsidae), Antalya-Korkuteli Yöresi'nde yeni bir tehdit olarak ortaya çıkmıştır. Bu sinekler tarafından bulaşıklığın, yöredeki mantar yetiştirme depolarının yaklaşık % 70'ini etkilediği tahmin edilmektedir. Korkuteli Yöresi'nde şuana kadar; Sciaridae familyasından 3, Phoridae familyasından 1, Cecidomyiidae familyasından 8 ve Scatopsidae familyasından 3 olmak üzere toplam 15 sinek türünün kültür mantarlarında zarara yol açtığı tespit edilmiştir.

1. Introduction

In many parts of Turkey (especially in the Antalya-Korkuteli district), mushroom cultivation has recently become very popular and is a promising new industry, with many new businesses developing every year (Akkaya et al. 2001). Main mushroom-producing areas in Turkey are located in the Western Mediterranean (Antalya, Burdur and Isparta), the Marmara (Kocaeli, Istanbul, Bursa, Sakarya, Yalova, Tekirdag, Bilecik and Balikesir), the Black Sea (Kastamonu, Bolu, Zonguldak, Samsun, Amasya, Tokat, Sinop, Ordu, Giresun, Trabzon and Artvin), and the Central Anatolia (Ankara and Kirsehir) regions, but small quantities are also produced in the East (Erzurum) and the West Anatolia (Mugla, Denizli and Izmir) (Fig. 1) (Erkel 1992, 2000, 2004; Gunay and Peksen 2004; Erler and Polat 2008; TUIK 2012).

Compost production and mushroom cultivation are two complementary components of mushroom production in Turkey. Total fresh mushroom production of the country has increased 29-fold in the last 29 years, from about 1.400 tons in 1983 to about 41.000 tons in 2012, and the Antalya-Korkuteli district (in South-Western Turkey) alone produces more than

60% of the total compost production and approximately 50% of the fresh mushrooms sold in the whole country (TUIK 2012). Although the white button mushroom, *Agaricus bisporus* (Lange) Imbach, is the most commonly grown mushroom species in Turkey, accounting for up to 95% of the total mushroom production (Aksu 2003; Erkel 2004; TUIK 2012), some other species, namely, *A. bitorquis* (Quel.) Sacc.; oyster mushrooms, *Pleurotus ostreatus* (Jacquim Fries) Kummer, *P. sajor-caju* (Fr.) Singer, *P. djamor* (Rumph.) Boedijn., *P. citrinopileatus* (Fr.) Singer, and *P. eryngi* (Dheengri); shiitake mushroom, *Lentinus edodes* (Berk.) Singer; maitake mushroom, *Grifola frondosa* (Dickson: Fries) Gray; reishi mushroom, *Ganoderma lucidium* (Ling Zhi); lion's mane mushroom, *Hericium erinaceus* Pers; enokitake mushroom, *Flammulina velutipes* (Curt.-Fr.) Karst.; and wood ear mushroom, *Auricularia polytrica* (Mont.) Saccardo are currently cultivated on a commercial scale for specific marketing areas in Turkey (Ilbay and Atmaca 2004; TUIK 2012).

Figure 1. Main mushroom-producing areas in Turkey (from Erler and Polat 2008).

In Turkey, the cultivation of *A. bisporus* started in the early 1960s in the Marmara (Kocaeli) and Central Anatolia (Kırşehir) regions and then extended to the other regions (Fig. 1) (Erkel 1992; Aksu et al. 1996). The most common technique used in the cultivation of *A. bisporus* is indoor bag cultivation (Erkel 2000; EYYDB 2003; Aksu 2006). Since indoor bag cultivation system is very labor-intensive and has several very undesirable consequences, the block cultivation system has recently become more popular than indoor bag cultivation system in some mushroom-growing regions, like the Marmara and West-Mediterranean regions. This review study dealt with mushroom flies affecting the cultivation of *A. bisporus* and alternative control possibilities against these fly pests in the Antalya-Korkuteli district.

2. Mushroom flies

Globally, commercial production of the cultivated mushroom, *A. bisporus*, is affected by a number of fly pests wherever the crop is grown (Hussey et al. 1974). In general, there are three fly pest groups most commonly encountered in mushroom-producing areas in many parts of the world as well as in Turkey. These are the sciarid flies (*Lycoriella* spp.) (Diptera: Sciaridae), the phorid fly [*Megaselia halterata* (Wood)] (Diptera: Phoridae) and the cecid flies [*Heteropeza pygmaea* Winnertz and *Mycophila speyeri* (Barnes)] (Diptera: Cecidomyiidae), and these fly pests are a consistent problem for growers throughout the world (Wyatt 1963; Clift 1979; White 1985; Kim and Hwang 1996; Erler and Polat 2008; Cevik 2011). However, in recent years the scatopsid flies (Diptera: Scatopsidae) have arisen as a serious new threat to the cultivated mushrooms in the Antalya-Korkuteli district (Basbagci 2012; Basbagci and Erler 2013). In the surveys carried out between 2004 and 2013, fifteen fly species were found to be associated with cultivated mushrooms in the Antalya-Korkuteli district (Table 1).

All these fly pest groups generally occur together in a mushroom culture. Their damage to mushroom crop is caused in two ways: (1) by the larvae feeding directly from on mycelia and mushrooms, and (2) by the adults acting as vectors for the introduction of disease agents, nematodes, mites, and other contaminants (Clift 1979; Clancy 1981; Wetzel 1981; White 1981). In addition, adults of all these flies are a constant nuisance to picking staff.

In Turkey, mushroom flies have been regarded as secondary pests of cultivated mushrooms until the 2000's. However, in the last decade mushroom flies have become a serious insect pest groups in the mushroom growing cellars in the Antalya-Korkuteli district.

Table 1. Harmful fly species associated with cultivated mushrooms in the Antalya-Korkuteli district

Family	Species	Year of Detection
Sciaridae	*Lycoriella auripila* (Winnertz)	2002 /2003
	L. ingenua (Dufour)	2002/2003
	L. solani (Winnertz)	2002/2003
Phoridae	*Megaselia halterata* (Wood)	2002/2003
Cecidomyiidae	*Heteropeza pygmaea* Winnertz	2011
	Lestremia cinerea (Macquart)	2011
	L. leucophaea (Meigen)	2011
	Mycophila speyeri (Barnes)	2011
	M. barnesi Edwards	2011
	Henria spp. (3 species, undetermined)	2011
Scatopsidae	*Scatopse notata* L.	2012
	Scatopse spp. (2 species, undetermined)	2012

2.1. Mushroom sciarid flies

Mushroom sciarids, commonly known as "dark-winged fungus gnats", are small (3-6 mm), delicate, black-gnat like flies with large compound eyes and long thread-like antennae, which are held characteristically erect. Their larvae are white, legless, fairly active maggots, which vary from 6-12 mm in length when mature (Fletcher and Gaze 2008).

Mushroom sciarids have a very low economic threshold, and cause losses in yield due to larval damage to compost affecting the structural features of compost, mycelium and sporophores (Clift 1979; White 1985). Although the larvae of sciarids prefer to feed on the compost itself, they nibble on developing mycelium, and damage primordia and mature sporophores by tunneling into the stipes (Hussey and Gurney 1968; Clift 1979). The adult flies are capable of causing damage to a crop, not directly, but as a result of contaminating pre-packed mushrooms. They are also capable of spreading the spores of *Verticillium* spp. and probably other pathogens such as *Cladobotryum* spp. have also been said to be spread by the adults of these flies (Fletcher and Gaze 2008). The economic threshold for sciarid larvae is virtually zero necessitating chemical control at very low larval densities (Kielbasa and Snetsinger 1980; White 1986). Great economic losses caused by sciarid fly pests in the mushroom industry have been reported from Australia, the United States, the United Kingdom and South Korea (Cantelo 1979; Clift 1979; White 1985; Kim and Hwang 1996).

In Turkey, only three species of mushroom sciarid flies (Genus: *Lycoriella* Frey) have been reported so far (Civelek and

Onder 1996; Erler and Vurus 2004). In a two-year survey study carried out in the Antalya-Korkuteli district, three sciarid species, namely, *Lycoriella auripila* (Winnertz), *L. ingenua* (Dufour), which was the first record for the Turkish fauna, and *L. solani* (Winnertz), were detected in mushroom growing cellars in the district. Of the three sciarid species determined in the surveys, *L. solani* was the most common species, accounting for up to 61% and 65% of the total population of mushroom sciarid flies in 2002 and 2003, respectively (Erler and Vurus 2004). In another survey study on mushroom flies, *L. solani* was determined to be the most common species in the mushroom growing cellars in Izmir province (in Western Part of Turkey) (Civelek and Onder 1996). Because the sciarid species prefer cool temperatures and are most active when outdoor temperatures are between 10 and 24°C (Coles 2002), the threat of infestation is greatest from March to May and September through late November (Erler and Polat 2008). This threat is diminished during the hottest part of the summer, especially under dry conditions.

2.2. Mushroom phorid flies

The phorids, also known as "hump-backed flies", are small (2-3 mm) and resemble diminutive houseflies in appearance. Phorid flies are larger than sciarids, with very short antennae and a characteristic hump-back. Their larvae are creamy-white legless maggots (1-6 mm long) with a pointed head, and a blunt rear end (Fletcher and Gaze 2008).

The larvae of mushroom phorids are obligate mycelial feeders and in this way they are able to cause a reduction in yield. Although direct damage to mushroom crop by phorid larvae is not very important (Rinker and Snetsinger 1984), the presence of the species must be avoided as the adults are vectors of the dry bubble disease, *Verticillium fungicola* (Pretiss.) Hassebt. (White 1981). Phorid flies, by acting as fungal vectors, pose a much greater threat to the mushroom crop in this way than they do as a result of their own feeding damage.

In a survey study carried out in the Antalya-Korkuteli district, *M. halterata* was found the only phorid fly species attacking to the cultivated mushrooms (Erler and Vurus 2004). The presence of this species in the mushroom growing cellars in İzmir province was reported by Civelek and Onder (1996). Apart from these two studies, there is no other work on the determination of mushroom flies in Turkey, including mushroom phorids. Phorid flies prefer warmer air temperatures and drier conditions in the substrate (Coles 2002) and therefore are most common during April-October (Erler and Polat 2008).

Although there is another mushroom phorid species, *Megaselia nigra* (Meigen) (Black mushroom phorid), that is frequently seen on wild mushrooms, it is an uncommon pest of the cultivated mushrooms (Fletcher and Gaze 2008).

2.3. Mushroom cecid flies

The bodies of the adults of these flies are 3-4 mm long, and their swollen abdomens are dull orange in color, depending on the species. As their legs are very long and slender, adult cecids resemble mosquitoes in appearance. A number of different cecids have so far been recorded as pests on mushrooms. Some are paedogenetic [i.e. they reproduce by paedogenesis, first described by Wagner (1862), in which mother larvae give rise to daughter larvae], others are not (Fletcher and Gaze 2008). The white or orange mushroom cecids, *Heteropeza pygmaea* Winnertz and *Mycophila speyeri* (Barnes), respectively, are the most common and economically important. A third species, *Mycophila barnesi* Edwards (Mushroom yellow cecid), has also been found, but as it develops more slowly than the other two species, it is generally not seen until the third or subsequent flushes. All these three species are obligate mycelial feeders and reproduce by paedogenesis, a process that eliminates the adult insect stage. In a mushroom cultivation environment, i.e. high temperature and humidity, cecids can produce a new generation every 4-7 days and each 'mother' larva can produce up to 12 new larvae so numbers can increase exponentially. This makes them difficult to control chemically (Wyatt 1963). The non-paedogenetic cecid species, *Lestremia cinerea* (Macquart) and *L. leucophaea* (Meigen), are very occasional pests of cultivated mushrooms. *Henria* spp. are the cecid species that can reproduce both by larval paedogenesis and by sexual reproduction. Laboratory and field tests carried out in Taiwan on the biology of the mushroom pest *Henria* spp. showed that their reproduction was by larval paedogenesis when food was abundant and microclimatic conditions favourable, however, under unfavourable conditions, sexual reproduction occurred, adults appearing only in April or May (Lin and Ni 1978).

In the surveys carried out in the Antalya-Korkuteli district, eight species of mushroom cecids, namely *H. pygmaea*, *L. cinerea*, *L. leucophaea*, *M. speyeri*, *M. barnesi* and *Henria* spp. (three species of the genus *Henria*, that have been under evaluation) were determined (Cevik 2011; Cevik and Erler, unpublished data). Although all these cecid species generally occur together in a mushroom culture, *H. pygmaea* and *Lestremia* spp. are by far the most common species of mushroom cecids, approximately 60% of the total cecid fly population captured in the surveys.

Although the larvae of mushroom cecids are found in decaying plant and animal material and generally prefer to feed on the compost itself, they are obligate mycelial feeders as with the phorids (Cevik 2011). Probably, the most important damage of mushroom cecids is that their adults are a constant nuisance to picking staff and act as vectors for some mushroom diseases arising from bacteria, viruses, viroids and other pathogens (Personal observations). Since they have high reproductive potential at the temperatures from 24°C to 30°C, suggested economic thresholds for mushroom cecids range from virtually zero to 5 individuals. Therefore, most mushroom growers in the Antalya-Korkuteli district find mushroom cecids to be one of the most challenging fly pest groups in warmer air temperatures and more humid conditions in the substrate (from April to October).

2.4. Mushroom scatopsid flies

The scatopsids, also known as "minute black scavenger flies" or "dung midges", are generally small, sometimes minute, dark flies (from 0.6 to 5 mm). In general, they resemble black flies (Simuliidae) in appearance, but usually lack the humped thorax characteristic of that family (Wikipedia 2011).

Although mushroom sciarids (*Lycoriella* spp.) and phorids (*M. halterata*) are the most common fly pests of the commercial mushroom industry in the Antalya-Korkuteli district (Erler and Vurus 2004; Erler and Polat 2008; Erler et al. 2009a, b, 2011), the scatopsids have recently arisen as a serious new threat for cultivated mushrooms (Basbagci and Erler 2013). It is surmised that all the mushroom growing cellars in the district have been affected by the infestation of these flies (Korkuteli Mushroom Growers' Association). In a study carried out in the Antalya-Korkuteli district, several species of the scatopsids were determined (Basbagci 2012). Although all these species generally occur together in a mushroom culture, *Scatopse notata* L. (Black compost fly) is the most common scatopsid in the district, about 40% of the total scatopsid fly population captured in the surveys (Dr. Paul Beuk, personal communication).

The larvae of most scatopsid species are unknown, but the few that have been studied have a rather flattened shape and are terrestrial and saprophagous. *S. notata* is a cosmopolitan species whose larval stages are found in decaying plant and animal material (Cook 1974). Although their larvae generally prefer to feed on the compost itself, they nibble on developing mycelium, damage primordia and sometimes tunnel into the stipes of young sporophores (Basbagci 2012). Probably, the most important problem with mushroom scatopsids is that their adults are a constant nuisance to maintenance staff and act as vectors for some mushroom diseases arising from bacteria, viruses, viroids and other pathogens (Personal observations). Therefore, the tolerance for mushroom scatopsids is virtually zero. In addition, because of their high reproductive potential at temperatures from 24°C to 30°C (Zhang et al. 2009), most mushroom growers in the Antalya-Korkuteli district find mushroom scatopsid flies to be the most challenging fly pest group in warmer air temperatures and more humid conditions in the substrate (during the summer period).

3. Control of mushroom flies

Cultivated mushrooms are the most valuable protected crop in Turkey; however, mushroom growing is the only horticultural commodity lacking an alternative to chemical control of pests and diseases. In fact, the availability of crop protection products for use in mushroom cultivation in the global scale is very limited. Although there is no registered insecticide available to control mushroom flies in Turkey, most mushroom producers use products registered for other agricultural pests, such as caterpillars, aphids, thrips, fruit flies, etc. (Basım 2004; Erler and Vurus 2004). Direct or chronic toxicity to applicators; or to consumers caused by unacceptable residues in food is an important problem in mushroom fly control with conventional pesticides.

Since mushroom flies have recently received attention as pests in Turkey, there is not so much literature on their control. In the Antalya-Korkuteli district, the control programs applied against mushroom flies are generally reliant on good management (good hygiene, compost pasteurization, fly screening, fumigation of rooms, etc.) and the use of conventional pesticides. The latter may be incorporated into either the compost or casing layer, watered on during cultivation, or applied as a wall or space spray to control their adults. These measures may provide adequate control if adhered to. However, pesticide resistance problems have been detected and application of certain pesticides at the casing layer has caused mycotoxic side-effects, resulting in yield reductions (Erler et al. 2009a, b, 2011). Additionally, many pesticides used in mushroom cultivation have persistence, which may lead to the presence of residues.

Mushroom sciarids are predominantly casing inhabitants and the usual chemical control is by treatment of the casing with selective pesticides, like Dimilin (diflubenzuron). Adults are controlled by space treatment with insecticidal smokes or fogs. The cecids are less common in cool seasons as hygiene and careful selection of casing materials eliminate them as a problem. However, as with the phorids, there is no pesticide available for use against them. Because mushroom scatopsids are a new fly pest group for mushroom cultivation in Turkey, there is no control method or material for their effective control. However, some producers use chemicals from various groups of insecticides including organophosphates, pyrethroids, carbamates, neonicotinoids, etc., although none of them are approved insecticides for the control of these insects (Basbagci and Erler 2013). The best control for all of the mushroom flies is strict sanitation, exclusion and farm cleanliness.

The Turkish Ministry of Food, Agriculture and Livestock aims at reducing pesticide use in mushroom cultivation. So, in recent years, increasingly stringent government regulations on pesticides and consumer pressure groups discourage their use in view of the associated human health concern and imply that alternative fly control. To develop sustainable methods for control of mushroom flies, new control agents that are safe for non-target organisms (humans and non-hazardous organisms) need to be evaluated. In a study by Erler et al. (2009a), 8 botanical materials (2 commercial neem-based products, Neemazal-T/S and Greeneem oil, and 6 hot-water plant extracts, namely; *Inula viscosa* L., *Melisa officinalis* L., *Ononis natrix* L., *Origanum onites* L., *Pimpinella anisum* L., and *Teucrium divericatum* Sieber) were evaluated for their potential in controlling mushroom phorid fly (*M. halterata*) by soil drench, to sufficiently wet the top 10-cm soil surface layer where larvae are found. Efficacy of the test materials was evaluated by numbers of emerging adults and damage rates of mushrooms by larvae, and compared with those of negative (water-treated) and positive (chlorpyrifos-ethyl-treated) controls. All the botanical treatments caused significant reductions in mean number of emerging adults and larval damage rates compared to negative control. Reduction in adult emergence in both neem treatments was greater than that of positive control. While Neemazal and *O. onites* extract had significantly lower larval damage rates than the positive control, there were no significant differences among the treatments with chlorpyrifos-ethyl, Greeneem oil, and *P. anisum*, in terms of larval damage rates. In another study by Erler et al. (2009b), 2 commercial microbial products [a bacterial larvicide, *Bacillus thuringiensis* var. *israelensis* Berliner (*Bti*), commercially available as Gnatrol (Valent Corp., Walnut Creek, CA), and an entomopathogenic nematode, *Steinernema feltiae* (Filipjev) Wouts, Mracek, Gerdin & Bedding, commercially available as Entonem (Koppert Biological Systems, The Netherlands], and 1 biologically-derived insecticide (microbial by-product), spinosad, commercially available as Laser (Dow AgroSciences, Indianapolis, IN, USA), were evaluated for their efficiency in controlling *M. halterata* by soil drench. The efficacy of the products were evaluated by numbers of emerging adults and damage rates of sporophores by larvae, and compared with those of negative (water-treated) and positive (chlorpyrifos-ethyl-treated) controls. Treatments with the microbial products or by-product had significantly lower numbers of emerging adults than those observed in water-treated control. There were no significant differences in adult emergence among the 3 microbial products/by-product and the chlorpyrifos-ethyl-treated control. Each of the microbial-based products reduced the incidence of sporophore damage by the larvae and resulted in significantly lower damage rates when compared to the water-treated control. In a recent study, alternative control possibilities were investigated against mushroom scatopsid flies (*Scatopse* spp.), 4 plant essential oils, namely pennyroyal (*Mentha pulegium* L.), sage (*Salvia tomentosa* Miller), wild thyme (*Thymbra spicata* L. var. *spicata*) and savory (*Satureja thymbra* L.), and their main components (pulegone, β-pinene, carvacrol and thymol, respectively) were tested at various concentrations (0.5, 1, 5 and 10 µl/l air) and exposure periods (0.5, 1, 2 and 4 h) for their fumigant activity against adult scatopsids (Basbagci and Erler 2013). According to the results from the study, all the essential oils and their components tested showed fumigant toxicity in varying degrees, *M. pulegium* essential oil and its major component, pulegone, being the most active (after 0.5 h, LC_{50} = 0.17 and 0.13 µl/l air, respectively). After a 4-h exposure period, both the oil and the component produced 100% mortality at all the concentrations tested. Even after a shorter exposure period (2 h), they achieved the same mortality level at all the concentrations, except for the lowest dose (0.5 µl/l air). All the responses were found test material-exposure period- and concentration-dependent.

In conclusion, the results from the above-mentioned studies suggest that microbial-based products and botanical materials as both contact (plant extracts) and fumigants (essential oils and their components) may be potential alternatives to conventional insecticides in controlling mushroom flies. The use of microbial-based products and botanical derivatives in mushroom fly control instead of synthetic insecticides can reduce unacceptable residues in mushrooms and preserve both human health and environmental quality.

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