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The Diversity and Ecological Roles of Visitor Insects on *Ganoderma* sp. Fruiting Body

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ABSTRACT

Pathogenic fungi's fruiting bodies may interact with other creatures such as insects. The purpose of this study was to better understand and identify the diversity of insect visits to Ganoderma sp. fruiting bodies, as well as their ecological responsibilities. From August to October 2022, this study was carried out at the Faculty of Forestry, Universitas Gadjah Mada Arboretum. Ganoderma sp. fruiting bodies were examined at three separate times: morning, afternoon, and evening. Insect visitor diversity was measured with diversity indices (*H*'), evenness (*E*'), and similarity (*S*'). A one-way ANOVA was used to investigate the effect of fruiting body category and observation period on insect abundance on fruiting bodies. The research findings revealed that the community of insect visitors to *Ganoderma* sp. fruiting bodies comprised 5 orders, 14 families, and 24 morphospecies. The dominant insect families were *Schizopteridae* and *Meinertellidae*, with dominant roles as predators (2 species), decomposers (2 species), and mycophages (4 species). Fruiting body categories influenced the families *Scolytidae*, *Coccinelloidea*, and *Schizopteridae*, but not *Formicidae*. The observation times indicated significant differences in the abundance of *Scolytidae* and *Schizopteridae*. Insects potentially serving as vectors carrying *Ganoderma* sp. fungal spores include *Scolytidae*, *Coccinelloidea*, *Staphylinidae*, *Drosophilidae*, *Formicidae*, and *Schizopteridae*. Information on visiting insects, especially those that potentially carry *Ganoderma spp.* spores, is crucial for understanding the spread of these fungal spores. This information can also aid in designing more effective control measures, including management of insect vectors.

Keywords: community, insect activities, insects' role, pathogen

INTRODUCTION

Universitas Gadjah Mada (UGM) is a campus with vegetation management carrying the Green Way concept consisting of a Closed System (CS) with the functions of water absorption, air conditioning, and open space. Suitable vegetation types that can grow well were selected to fulfil the ecological function of an area. The results of observations of the health of trees that make up the vegetation in the UGM area show that most of the trees are damaged (mild to severe) by the *Ganoderma* sp. fungus (Utomo 2021). *Ganoderma* sp. is parasitic on living trees (Widyastuti *et al.* 1998) and saprophytic on dead trees (Zakaria *et al.* 2009; Hidayati and Nurrohmah 2015). Transmission of disease by *Ganoderma* sp. can occur through the transfer of spores (Herliyana *et al.* 2012), which is assisted by three agents: water, wind, and animals (Buczacki 1989; Taskirawati 2015). One animal group that can act as vectors is insects (Tuno 1999; Yamashita *et al.* 2015; Elliott 2020).

Insects are a group of invertebrates whose presence is dominant on the Earth's surface (Meilin and Nasamsir 2016). The high number of insects is because they can survive in a variety of environments, have a high reproductive capacity, and could save themselves from predators (Borror *et al.* 1992). Insects can be found in almost all habitats, including soil, fresh water, and air (Campbell *et al.* 2003). The diversity and abundance of insects in the environment are influenced by abiotic (temperature, humidity, water, soil, and altitude) and biotic factors (food availability) (Suwondo *et al.* 2015; Ricco *et al.* 2019; Aveludoni 2021). One of the efforts to control *Ganoderma* sp. fungal attacks is to know how it spreads, assisted by insects. Several studies have discussed the interactions between insects and fungi, including the interaction of Mycodrosophila flies with *Elfvingia applanata* fungi (Tuno 1999), ambrosia beetles with *Raffaelea lauricola* fungi (Carrillo *et al.* 2014), mycophagous beetles with fungi of the order Polyporales (Yamashita *et al.* 2015), and beetles with Ganoderma fungi or other fungi (Elliott 2020). However, research on insects associated with Ganoderma fungi in Indonesia is limited.

This study aims to determine the diversity and role of insect visitors in the fruiting bodies of *Ganoderma* spp. Furthermore, the factors that influence the presence of these insect visitors will be studied by answering the following questions: (1) What insects are found visiting the fruiting bodies of *Ganoderma* sp.? (2)

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Are there differences in insect visitor communities in different fruit-body age categories and observation times? (3) Are there any insect visitors to the fruiting bodies that have the potential to be insects carrying fungal spores?

METHODS

Time and Location

Insect collection was conducted on the fruiting bodies of *Ganoderma* sp. found in the Arboretum of the Faculty of Forestry, UGM, Sleman, Yogyakarta (Figure1). The collected insects were identified at the Forest Protection and Health Laboratory. The insect collection was conducted from August to October 2022.

Insect Observation and Collection

This study employed a survey method to observe the insect community through direct visual observation and manual collection using collection bottles and brushes. Insects were collected at three designated observation periods throughout the day: morning (08:00–10:00 AM), mid-day (11:00 AM–01:00 PM), and afternoon (02:00 PM–04:00 PM). The fruiting bodies of *Ganoderma* sp. are categorized into three groups: young, intermediate, and mature, based on the shape and color of the fruiting body (Widyastuti *et al.* 1998, Luangharn *et al.* 2020) (Figure 2a–c). In this study, there were variations in the number of fruiting bodies for young, medium, and old fruiting bodies, consisting of 9, 14, and 16 fruiting bodies, respectively. The total number of fruiting bodies was 39.

Insect collection was carried out three times a week for three months (August–October), and a total of 54 insect collections were obtained. Insects that visited the fruiting body at each observation time were documented and carefully collected using a brush. Furthermore, the insects were stored in a collection bottle to be taken to the laboratory and identified to the order, family, and morphospecies levels using a microscope (OPTO-EDU Stereo Microscope A23.1502). Identification was carried out using morphological characteristics based on several related studies, such as Borror *et al.* 1992; White and Borror 1998; Bugguide.net).

Figure 1 Map showing the locations of *Ganoderma* sp. fruit bodies in the FKT UGM Arboretum.

(a) (b) (c)

Figure 2 The fruit bodies of *Ganoderma* sp. are classified into three categories: (a) young, (b) intermediate, and (c) mature.

The collected insects were grouped based on their order, family, and morphospecies. Environmental conditions, such as temperature and humidity, were measured on the surface of the fruit body at a height of 0 cm using a TA318 Thermohygrometer and a Luxmeter Smart Sensor AS823 to measure the sunlight intensity. Environmental conditions, based on the month and hour of observation, showed varying results (Tables 1 and 2).

Insect Communities and Influencing Factors

Information on insect communities visiting *Ganoderma* sp. fruiting bodies was obtained using data on orders, families, and morphospecies. Furthermore, insect data were grouped based on fruit body categories and observation times. Several ecological indices were used to determine the diversity of insects visiting *Ganoderma* sp. fruiting bodies, including the Shannon-Weiner diversity index (*H*'), using the following formula:

$$H' = -\sum_{i=s}^{s} pi \ln pi$$

and criteria *H*'<1.5 = low; 1.5≤*H*' ≤ 3 = moderate; and *H*'>3 = high (Krebs 1989). The evenness index (*E*') was calculated using the 0–1 criterion, where the closer *E*' was to 1, the lower the possibility of insects dominating the community (Fachrul 2009). Furthermore, the similarity index (*S*') was calculated using the 0–1 criterion, where the closer *S*' is to 1, the higher the similarity of insect species in the two habitats being compared (Indriyanto 2006). The individual insect data obtained were presented in a graph of the average individual abundance of insects (Microsoft Excel 365, Office 365). Individual insect data at the family level were used to determine the effect of fruit body category and observation time on the abundance of each individual insect using one-way ANOVA (SPSS software version 20).

Ecological Role of Visiting Insects

The ecological role of insects was identified using references from journals, books, and other related references. In addition, insect morphology was observed using a Stereo Microscope A23.1502 and a scanning electron microscope (SEM, Hitachi TM4000Plus) to observe the possible presence of fungal spores on the body parts of insects.

RESULTS AND DISCUSSION

Insect Community

Observation of the total insect community revealed 5 orders, 14 families, and 24 insect morphospecies (Table 3). The orders obtained were Hemiptera, Archaeognatha, Diptera, Hymenoptera, and Coleoptera, with different abundance percentages based on the category of *Ganoderma* sp. fruiting bodies (Figure 3a) and observation time (Figure 3b). The order Hemiptera was dominant in young (78%) and medium (64%) fruiting bodies, while Archaeognatha was dominant in old fruiting bodies (47%) (Figure 3a).

The Archaeognatha order showed an increase in number following the age of the fruiting body; conversely, Hemiptera tended to increase in young fruiting bodies. The Archaeognatha order usually lives under rocks, tree trunks, and peeled tree bark (Ma *et al.* 2015), so it is thought to have adapted to living in the fruiting bodies of *Ganoderma* sp., which are usually found on tree trunks. The Meinertellidae family (Archaeognatha) found in this study was dominant in old fruit bodies that were no longer productive or had died and were starting to decompose because of their role as decomposers that decompose organic matter from dead organisms (Day *et al.* 2019).

The order Hemiptera plays a role not only as an herbivore, but also as a predator, mycophagus, and parasite (Muñoz 2007). The Hemiptera order found in this study was Schizopteridae (predator) and Pyrrhocoridae (phytophagus), but the Schizopteridae population was more dominant, so it was taken as a

Table 1 Environmental conditions at Faculty of Forestry Universitas Gadjah Mada Arboretum based on observation month in the year of 2022

Month	Temperature (℃)				Humidity (%)				Light intensity (Lux)			
	Category of fruit bodies											
	Young	Intermediate	Mature	Average	Young	Intermediate	Mature	Average	Young	Intermediate	Mature	Average
August	28.95	26.65	29.54	28.38	80.24	72.18	70.29	74.24	137.23	369.20	237.33	247.92
September	27.39	28.83	28.23	28.15	82.29	78.00	76.30	78.86	221.00	471.83	321.83	338.22
October	27.74	28.54	27.01	27.77	90.03	86.31	87.28	87.87	172.34	623.17	181.54	325.68
Average	28.03	28.01	28.26	28.10	84.19	78.83	77.96	80.32	176.86	488.07	246.90	303.94

Table 2 Environmental conditions at Faculty of Forestry Universitas Gadjah Mada Arboretum based on observation time on three different months in the year of 2022

Month	Temperature (℃)				Humidity (%)				Light intensity (Lux)			
	Time											
	Morning	Mid-day	Afternoon	Average	Morning	Mid-day	Afternoon	Average	Morning	Mid-day	Afternoon	Average
August	27.24	29.66	29.84	28.91	80.85	72.15	71.83	74.94	136.33	336.50	218.33	230.39
September	27.28	28.53	28.42	28.08	80.29	76.00	76.00	77.43	219.00	359.83	307.83	295.56
October	26.84	27.74	27.31	27.30	91.13	87.08	87.58	88.60	199.00	775.17	183.50	385.89
Average	27.12	28.64	28.53	28.10	84.09	78.41	78.47	80.32	184.78	490.50	236.56	303.94

Table 3 Insects at the family and morphospecies levels in three categories (young, intermediate, and mature) of Ganoderma sp. fruit bodies observed at Faculty of Forestry Universitas Gadjah Mada Arboretum during August-October 2022

Order	Family	Number of morphospecies		
		Young	Intermediate	Mature
Coleoptera	*Scolytidae*	2	2	2
	Coccinelloidea	0	2	1
	Psephenidae	0	1	0
	Staphylinidae	0	1	1
Hemiptera	*Schizopteridae*	2	4	4
	Pyrrhocoridae	0	0	1
Diptera	*Drosophilidae*	0	1	1
	Psychodidae	0	1	0
	Ceratopogonidae	0	0	1
Hymenoptera	*Formicidae*	2	5	4
	Chalcidoidea	0	1	0
	Tenthredinidae	0	1	1
	Eucoilidae	0	0	1
Archaeognatha	*Meinertellidae*	1	1	1
Total		7	20	18

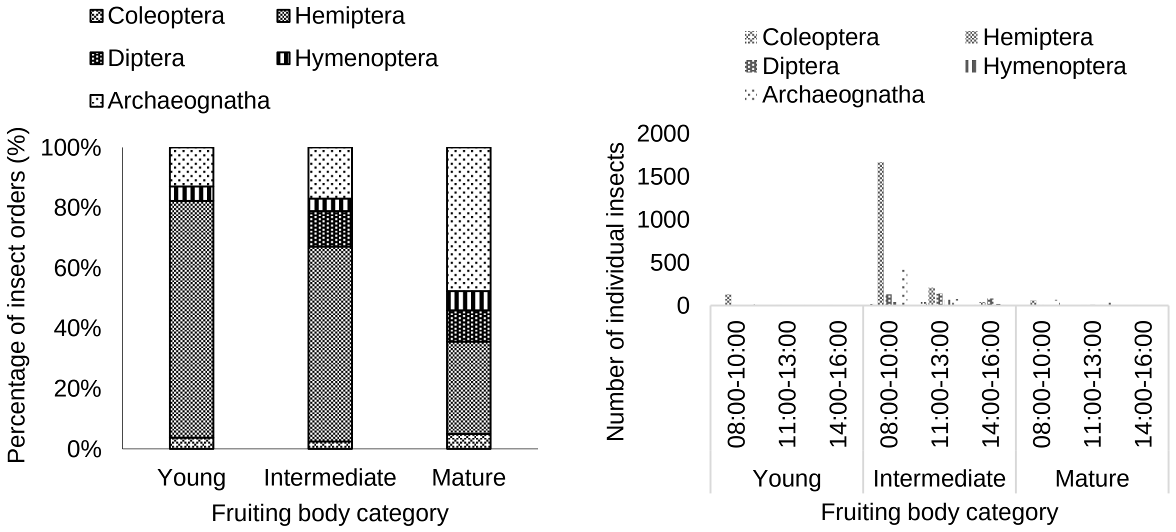

Figure 3 Insects visiting the fruit bodies of Ganoderma sp. across different categories (young, intermediate, and mature) observed at Faculty of Forestry Universitas Gadjah Mada Arboretum in August-October 2022. (a) Percentage of insect orders and (b) Number of individual insects categorized by order and observation time.

predator. The tendency of Hemiptera to increase in young fruit bodies is thought to be due to the lack of competition from other orders, such as Coleoptera (mycophagus) and Archaeognatha (decomposers), which prefer medium and old fruit bodies because they provide suitable food. The abundance of the order Hemiptera was the highest in intermediate fruit bodies due to the abundance of other visiting insects. The results of insect collections based on observation time show that insects tend to visit in the morning (08.00 am–10.00 am). This is in accordance with previous research, which stated that the orders Hymenoptera, Diptera, Coleoptera, and Hemiptera actively forage at 09.00–10.00 am (Sikdar *et al.* 2019), so they will visit the fruiting body in the morning as mycophagi or as predators that prey on visiting insects.

The identification results obtained were from 14 families and 24 insect morphospecies (Table 3). The fruit body category has varying morphospecies, namely, 7, 20, and 18 for young, intermediate, and mature fruit bodies, respectively. The highest number of morphospecies occurred in intermediate fruiting bodies and the lowest number occurred in young fruit bodies. This is thought to occur because the mushroom fruit-body category affects the morphospecies found.

Mushroom fruiting bodies serve various roles in insects, providing them with a food source, habitat for predators, and shelter (Taskirawati 2015). Several morphospecies identified in this study are believed to utilize fruiting bodies both as a source of food and a living space. Notably, members of the Scolytidae family (Coleoptera) are thought to use these structures as a food source (Setiawan 2017), whereas the Schizopteridae family (Hemiptera) utilizes them as a habitat (Scudder 2010). Additionally, active insects of the Formicidae family (Hymenoptera) traverse these fruiting bodies (Csata and Dussutour 2019). The calculated H' values for the three categories of fruiting bodies—young (0.56), intermediate (0.73), and mature (0.78)—indicate that the insect community associated with these structures falls within the low diversity category (Table 4). These results are supported by the E' values in young fruit bodies (0.66), intermediate (0.56), mature (0.62), and S' values between young and intermediate fruit bodies (0.48), young and mature (0.61), and intermediate and mature (0.22), indicating that there are types of insects that dominate (Table 5). The dominant insects are Schizopteridae (Hemiptera) in young fruit bodies, and Meinertellidae (Archaeognatha) in mature fruit bodies.

The results of this study indicate that Schizopteridae (Hemiptera) is the dominant insect in young fruiting bodies (>50%). In accordance with previous studies stating that Schizopteridae are predators (Scudder 2010), it is suspected that the abundance of other visiting insects has resulted in an increase in the number of Schizopteridae. The Meinertellidae (Archaeognatha) insect group dominated the mature fruit bodies (47.7%). These results are in accordance with previous studies, which stated that Meinertellidae are decomposer insects that play a role in decomposing organic matter from dead organisms (Day *et al.* 2019); therefore, they are dominant in mature fruit bodies that are no longer productive or have died and are starting to decompose.

Factors Influencing Insect Communities

In this study, significant differences were found in several famili es owing to the influence of fruit body category and observation time (Table 6). Fruit body category is also known to significantly affect insect abundance in the families *Scolytidae, Coccinelloidea, Schizopteridae*, and *Formicidae*. Meanwhile, the observation time showed significant differences in *Scolytidae and Schizopteridae*.

Insect abundance is influenced by biotic (food availability) and abiotic (temperature, humidity, water, and soil) factors (Suwondo *et al.* 2015; Ricco *et al.* 2019; Aveludoni 2021). The differences in temperature, humidity, and light intensity between the three categories of fruiting bodies at the three observation times were not significantly different (Tables 3 and 4). The temperature at the research location ranged from 27.12 to 28.9°C with a light intensity of 184.78 lux–555.83 lux, which are ideal conditions for the existence of insects (Handani *et al.* 2015; Purwanto *et al.* 2017). Furthermore, these environmental conditions can provide suitable conditions for insects to become active.

Previous research (Yamashita *et al.* 2015) has shown that the category of fruiting bodies can affect the abundance of insects because it affects the food available, especially for mycophagous insects. In this study, differences in mushroom fruiting body category had a significant effect on the average of the *Scolytidae, Coccinelloidea, Schizopteridae*, and *Formicidae* families. The *Scolytidae* family is an internal feeder mycophagous insect that burrows into the mushroom fruiting body to find food and create galleries (Rudinsky 1962), so many of the medium and old fruiting bodies are large because they can create a wider gallery system (Setiawan 2017). The *Coccinelloidea* and *Schizopteridae* families are predatory insects; therefore, they are often found in

Table 4 Diversity index (*H*') and evenness (*E*') of insects in three different fruit body categories

Category	Diversity index (*H*')	Evenness (*E*')
Young	0.56	0.66
Intermediate	0.73	0.56
Mature	0.78	0.62

Table 5 Similarity index (*S*') of insects in three different fruit body categories

Category	Young	Intermediate	Mature
Young	-	0,48	0,61
Intermediate		-	0,22
Mature			-

Table 6 Results of ANOVA F values for the influence of fruit body category and observation time on insect abundance at the family level

Variable	Scol.	Coc.	Pse.	Sta.	Schiz.	Pyrr.	Dros.	Psyc.	Cera.	For.	Chal.	Tent.	Euc.	Mei.
Fruit body	6.77*	3.11*	2.01	1.52	6.41*	1.00	1.40	1.00	1.00	6.24*	1.00	0.50	0.50	1.63
Observation time	3.40*	1.93	0.50	1.52	3.81*	1.00	1.11	1.00	1.00	2.57	1.00	0.50	1.00	4.17

Remarks: Scol.= Scolytidae; Cocci.= Coccinelloidea; Pseph.= Psephenidae; Staph.= Staphylinidae; Schiz.= Schizopteridae; Pyrrh.= Pyrrhocoridae; Droso.= Drosophilidae; Psych.= Psychodidae; Cerato.= Ceratopogonidae; Form.= Formicidae; Chalci.= Chalcidoidea; Tenth.= Tenthredinidae; Euco.= Eucoilidae; Mein.= Meinertellidae. Significance is followed by * F<0,05 medium and old fruiting bodies that have a higher abundance of insects than young fruiting bodies. Abundant insects are food sources of predatory insects. Formicidae are thought to only pass through the fruiting bodies of *Ganoderma* sp. when they are active, because few studies have discussed ants as mycophagi. Ants are the most common insect visitors to mushroom fruiting bodies, but ants as insect visitors to mushroom fruiting bodies are thought to be predatory insects that prey on mycophagous insects (Epps & Penick 2018). Intermediate and mature fruiting bodies provide more insects than young fruiting bodies do.

Differences in observation time can also affect insect abundance (Allifah *et al.* 2020). In this study, we found that differences in observation time had a significant effect on the average of the Scolytidae and Schizopteridae families. Scolytidae are known to be active in the morning and afternoon (Putra *et al.* 2011) and are often found in the morning when looking for food and digging tunnels. Schizopteridae, which act as predators, are often found in the morning and afternoon because other insects are diurnal insects, namely insects that carry out their activities during the day (Alfianingsih *et al.* 2022). The Schizopteridae family is active when prey is abundant.

Ecological Role of Visiting Insects

Insect roles were identified as follows: parasitoids (0.05%), decomposers (15.60%), algivores (algae eaters) (15.63%), sanguivores (blood eaters) (0.02%), phytophages (1.14%), pollinators (0.02%), omnivores (3.48%), predators (52.85%), and mycophages (11.20%). Among these roles, predators, decomposers, and mycophages emerged as the dominant categories, each surpassing 10%, whereas the others, categorized as minor groups, remained below 10% (Figure 4a). Insects from the family *Meinertellidae*, known as decomposers, along with predators from *Schizopteridae*, were the most common in all categories of fruit bodies, accounting for over 90% of the total (Figures 4b and c). Additionally, mycophagous insects from the family *Scolytidae* were particularly prevalent in young fruiting bodies (Figure 4d).

The *Meinertellinidae* family is typically found in leaf litter near both living and dead trees as well as in rocky areas (Sanchez-Garcia *et al.* 2019). In this study, it was suggested that *Meinertellinidae* utilize the fruiting bodies of *Ganoderma* sp. as their habitat and exhibit vertical jumping behavior (Zhang *et al.* 2017) to reach the forest floor, where they can access energy sources such as organic matter, highlighting their role as decomposers.

The *Coccinelloidea* and *Schizopteridae* families are generalist predators with a wide range of prey (Hastuti 2011; Fitriani 2018; Henry 2019). The abundance of these two families of predatory insects can be caused by the abundance of other insect visitors to the *Ganoderma* sp. fruiting bodies, which are their food sources. The *Scolytidae* family dominates the insect community in the young fruiting bodies. This is in accordance with previous studies, which stated that as mycophagus, *Scolitydae*, prefers fresh fruit bodies (Lipkow and Betz 2005), while *Drosophilidae* prefers mushrooms that are starting to rot due to adaptation to other ecological functions as detritivores (Valer *et al.* 2016). The *Formicidae* family comprises omnivorous insects and was recognized in this study as possessing the largest number of morphospecies. Previous research has indicated that *Formicidae* are the most prevalent insect visitors to mushroom fruiting bodies (Epps and Penick 2018). In contrast, the low abundance of parasitoid insects is believed to stem from a lack of suitable hosts within the families Chalcidoidea and Eucoilidae (Hymenoptera).

Insects can fly and jump; therefore, they have the potential to be vectors of pathogenic fungal spores, including *Ganoderma* sp. (Taskirawati 2015). In this study, the insect families suspected to have the potential to be vectors for the spread of Ganoderma spores were Scolytidae, *Coccinelloidea*, *Staphylinidae*, *Drosophilidae*, *Formicidae*, and *Schizopteridae*. The *Drosophilidae* family has a morphology that supports the spread of spores in the form of fine hairs on its body, as shown in this study (Figure 5). Previous studies have explained that *Drosophilidae, Scolytidae, Coccinelloidea*, and *Formicidae* are potential spore-dispersal insects (Borror *et al.* 1992, Pulukadang, *et al.* 2014; Ashfaque *et al.* 2015; Rosnadi 2019). The *Staphylinidae* and *Schizopteridae* families are mycophagous insects with a mouth structure that allows them to act as spore-dispersed insects (Betz 2004; Scudder 2010).

CONCLUSION

This study showed that the insect community visiting the fruiting bodies of *Ganoderma* sp. consists of five orders, 14 families, and 24 morphospecies. Differences in fruiting body age (young, intermediate, and mature) and observation time significantly affected the presence of insect visitors, especially families (*Schizopteridae, Meinertellidae, and Scolytidae*). Insect visitor diversity was included in the low category, which indicates the presence of dominant insects. Insect visitors to the fruiting body are dominated by ecological factors, such as predators, decomposers, and mycophagi. Although not dominant, insect visitors to the fruiting body that have the potential to be carriers of Ganoderma spores come from the families *Scolytidae* (Coleoptera), *Coccinelloidea* (Coleoptera), *Staphylinidae* (Coleoptera), *Drosophilidae* (Diptera), *Formicidae* (Hymenoptera), and *Schizopteridae* (Hemiptera). Understanding insect visitors, particularly those who could act as vectors for pathogenic fungal

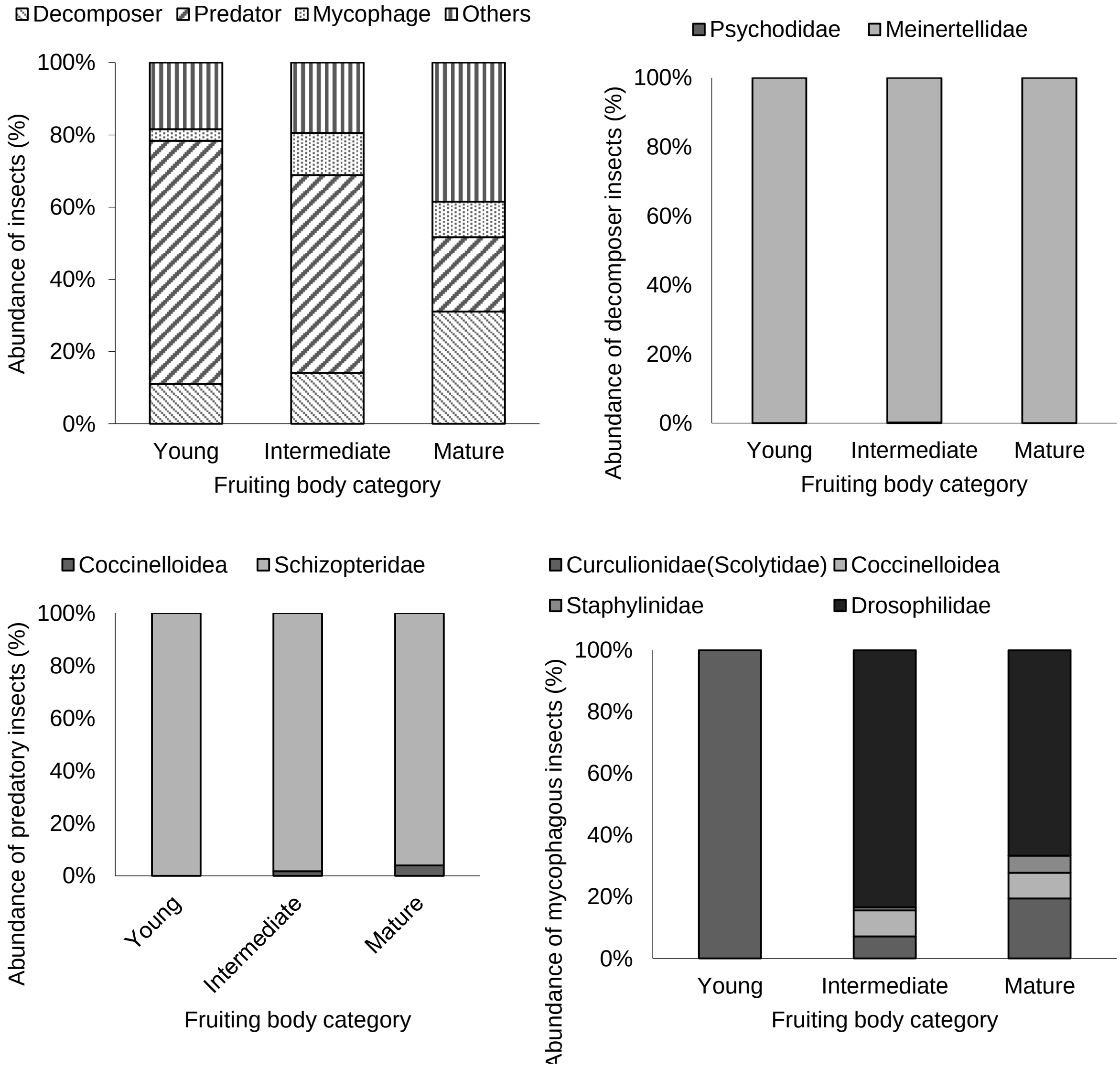

Figure 4 Percentage of relative abundance of insects visiting the fruit bodies of *Ganoderma* sp. (a) Abundance categorized by dominant role, (b) abundance of decomposer insects, (c) abundance of predatory insects, and (d) abundance of mycophagous insects.

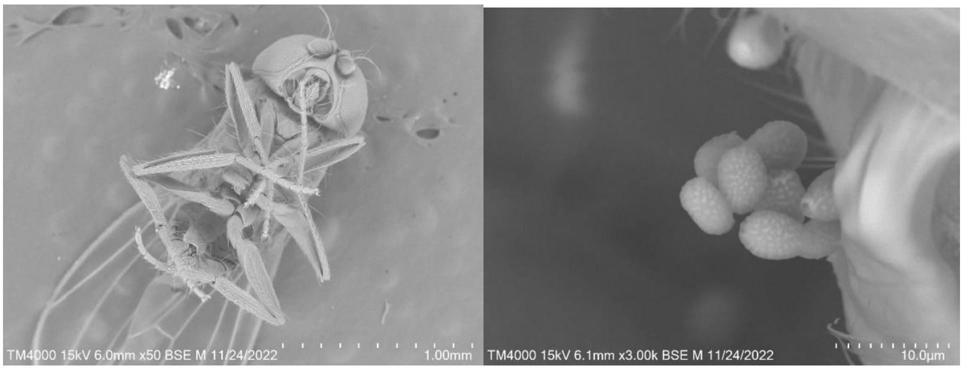

Figure 5 Results from SEM observations of the *Drosophilidae* family, illustrating spores adhered to the fine hairs on the bodies of Drosophilidae.

spores, is crucial for assessing the potential spread of *Ganoderma* sp. spores by these insect agents. Additionally, this information can provide more targeted control measures, including strategies for insect vector management.

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