Jurnal Biodjati 9(2):334–347, November 2024
e-ISSN : 2541-4208
p-ISSN : 2548-1606

JURNAL BIODJATI

http://journal.uinsgd.ac.id/index.php/biodjati

Ganoderma Diversity and Its Interactions with Hosts and Neighbouring Insects in Gunung Walat Educational Forest

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Received: Juny 28, 2024
Revise from: July 16, 2024
Accepted: November 29, 2024

DOI: 10.15575/biodja ti.v%vi%i.36749

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Abstract. *Ganoderma spp. is a genus of macrofungi in the Basidiomycota, comprising both saprophytic and phytopathogenic species. Ganoderma spp. prefers woody substrates and can attack various trees in the forest. While it often acts as a phytopathogenic fungus, it also serves an ecological role for surrounding insects, providing food and shelter. This study aims to determine the interactions and preferences of Ganoderma spp. with its hosts and to observe the interactions between Ganoderma spp. and surrounding insects. Research on these interactions was conducted through scan sampling exploration in the Gunung Walat Educational Forest. Identification of fungi, trees, and insects was based on morphological characteristics. A total of 155 fruiting bodies of Ganoderma were found. Three species of Ganoderma were successfully collected and described morphologically, both macroscopically and microscopically. Ganoderma spp. were found infecting Agathis sp., Schima wallichii, and Pinus merkusii trees. The fruiting bodies of Ganoderma spp. interacted with insects such as larvae, Trichomyrmex destructor ants, and Eumorphus marginatus beetles, which used the fruiting bodies as breeding and shelter sites.*

Keywords: *fruiting bodies, ganoderma, insects, interactions, phytopathogenic*

Citation
Mayra, M. T., Chan, C., Abdurrahman, N. H., & Putra, I. P. (2024). Ganoderma Diversity and Its Interactions with Hosts and Neighbouring Insects in Gunung Walat Educational Forest. *Jurnal Biodjati*, 9(2), 334-347.

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INTRODUCTION

Ganoderma is a genus of macrofungi in the phylum Basidiomycota, comprising both saprophytic and phytopathogenic species. Most *Ganoderma* species are reported as pathogens of woody plants. However, some species also have medicinal benefits, producing bioactive compounds such as polysaccharides, oligosaccharides, triterpenoids, peptides, alcohol proteins, and phenols that benefit health (Kües et al., 2015). The species of *Ganoderma* in the tropics are diverse. This fungus can damage forest trees and plantation crops such as oil palm, coconut, and cocoa (Tchoumi et al., 2018; Edy et al., 2020). *Ganoderma* generally has a semicircular shape resembling a fan or kidney, with colours ranging from dark red and reddish-brown to reddish black. The surface of *Ganoderma* appears shiny and has a woody texture (El Sheikha 2022; Ekiz et al., 2023).

The pathogenic nature of Ganoderma enables it to colonize specific host plants. Generally, *Ganoderma* causes heart rot in living and dead trees, primarily affecting the non-living wood tissue at the center (Fernando, 2008). This disease can spread and is considered one of the significant threats in forestry plant cultivation (Herliyana, 2012). The Gunung Walat Educational Forest hosts several tree species, including Agathis sp., Schima wallichii, and Pinus merkusii. Agathis sp. is one of the trees in this area that has been recorded as infected with Ganoderma spp. (Herliyana, 2012). Further studies are needed to investigate the infection in other tree species.

In addition to being pathogenic to woody trees, *Ganoderma* plays several ecological roles for surrounding organisms. Ganoderma's robust structure and specific compounds' presence facilitate interactions with various organisms, including insects. Mycophagy behaviour by insects towards *Ganoderma* is often observed. This behaviour is widely seen in the Agaricomycetes that form large fruiting bodies. According to Santamaria et al., (2023) animals, especially invertebrates, engage in mycophagy because fungi are an easily accessible source of nutrition. *Ganoderma* also provides ecological benefits as shade for small animals such as insects (Hathaway, 2018). The sturdy structure of *Ganoderma* can offer shelter for insects to live and breed under its fruiting bodies. Therefore, this research aims to determine the interactions and preferences of *Ganoderma* spp. with its hosts and to observe the interactions between *Ganoderma* and the surrounding insects.

MATERIALS & METHODS

Data Collection

The research was conducted in May 2024 in Mount Walat Education Forest, (6.9108° S, 106.8261° E, 723 m a.s.l, 349 ha) Bogor, West Java, Indonesia (Figure 1). The sampling site (100 ha) was dominated by Agathis sp., Schima wallichii, and Pinus merkusii. The data collection time was from 09.00-16.00 WIB for each three days. Specimens' analyses were carried out at the Laboratory of Department of Biology, IPB University.

Sample collection was conducted using the environmental exploration method. This method involves using the environment as the object of study and examining it scientifically (Ilhamdi et al., 2022). The process involves traversing specific paths to locate the desired samples. The exploration area includes regions where trees have died or locations with high abundance. The tools used in this research include a loupe, brushes, fungi (Luangharn et al., 2021), and an insect identification reference (Resh and Carde, 2009).

Description and Identification of Fungi

The basidiomata were collected and described based on macroscopic characters following Putra (2021). The microscopic characters observation based on Harahap et al., (2024). The observation data then prepared

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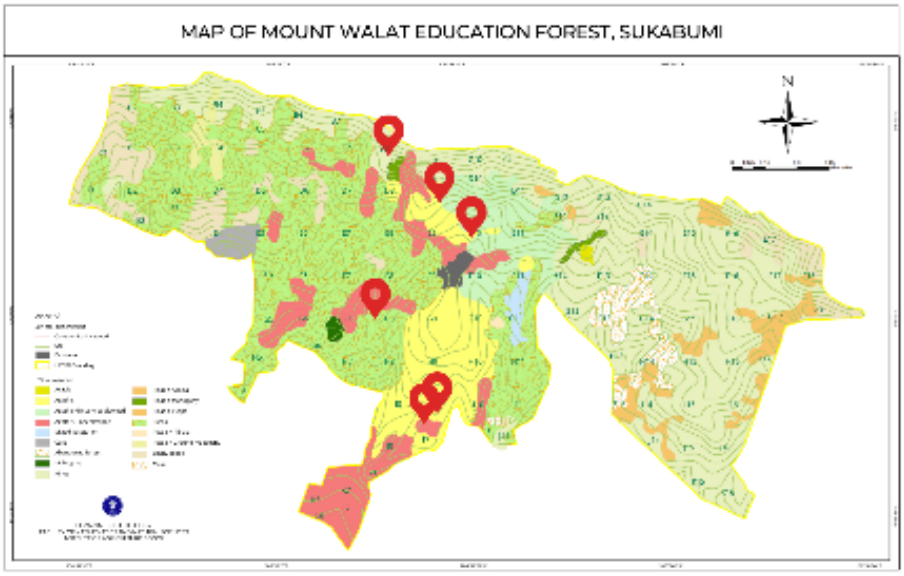

Figure 1. Map of sampling locations (red dotes) in Mount Walat Education Forest

as a fungal description. The description used related references for Ganoderma identification (Luangharn et al., 2021).

Host Tree Identification

Plant identification was conducted using the morphological identification method (Qomah et al., 2015). This method involves observing the characteristics of the specie includes examining the roots, buds, branches, stems, leaves, and other parts of the plant that can aid in identification. The identification references were also based on Gunung Walat Forest Map, the iNaturalist application, and the PlantNet application.

Insect Identification

Collection and identification of insects was done using the method of opportunistic sampling without trap. Morphological matching was conducted using the *iNaturalist* application and followed by verification through related reference (Resh and Carde, 2009).

Data Analysis

Data analysis was done using qualitative methods, and the results are shown through descriptions, tables, and figures.

RESULT AND DISCUSSION

Three Ganoderma species with 155 basidiomata encountered (Table 1) were successfully observed for their interactions with hosts of four tree species in Gunung Walat Educational Forest (Table 1). Three species which found have been taken from five different points (Figure 1). Ganoderma was encountered in individual trees with different conditions and planting. The number of Ganoderma observed indicates the preference of Ganoderma with Agathis. The highest rate of Ganoderma infection on Agathis could be due to the absence of resin. Resinous plants such as pine have a systemic swelling mechanism that induces resistance to pathogen (Ganoderma) infection. The ISR mechanism can accumulate large amounts of resin at the site of wounding, accumulation,

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and enhance anti-fungal activity (Suryantini and Wulandari 2018). The Agathis trees which colonized by Ganoderma was the dead wood.

The abundance of Ganoderma on dead Agathis can be possibly caused by two factors, infection of the wood trunk by Ganoderma after death and infection of the live wood trunk by Ganoderma until the tree dies and falls. Thus, the number of Ganoderma growing on dead wood is more than on live trees. Ganoderma has the tendency to attach to the stem part of plant organs living trunk. Ganoderma infection on the live trunk can be caused by openings made to obtain copal or tree resin, especially Agathis. An opening can cause direct contact of Ganoderma spores with tree tissue which facilitates the Ganoderma infection process on trees (Herliyana, 2012). Another Ganoderma attachment location that has a high tendency after the live trunk is the dead root (Fernando, 2008).

Table 1. Diversity of *Ganoderma* sp. and its attachment conditions on the host

Mushroom species	Host	Basidiomata location	Host condition	Number of Basidiomata
Ganoderma sp.1	Agathis sp.	Trunk	Dead	8
		Root	Dead	50
		Trunk base	Alive but leaves are deciduous	52
Ganoderma sp.2	Agathis sp.	Trunk	Dead	4
	Pinus merkusii	Trunk base	Alive but leaves are deciduous	4
	Schima wallichii	Trunk	Dead	17
Ganoderma sp.3	Schima wallichii	Trunk	Alive but leaves are deciduous	20
Total				155

Each of the *Ganoderma* found in the current study has different characteristics. Below the description of each *Ganoderma*, with the macroscopic and microscopic characteristics, the host, and the interaction between *Ganoderma* and its host.

Ganoderma sp.1

Ganoderma sp.1 has hard with a half-circular shape of fruiting body, white colour on the margin (Figure 2a-b), a red brown colour on the canter of basidioma, and produces extrudates (Figure 2c). This fungus prefers both dead wood and living tree substrate. It has been observed to grow in colonies both on dead wood substrates and on living trees.

Ganoderma sp.1 has a smooth, slippery, and non-porous surface texture on the upper basidioma. Exudate discharge is found on the top surface of *Ganoderma* sp.1. The lower surface of the *Ganoderma* sp.1 is white, porous (Figure 2d), and tends to be smooth. Hyphae on the top surface of *Ganoderma* sp.1 is septate (Figure 3a). The spores are oval-shaped (Figure 3b-c).

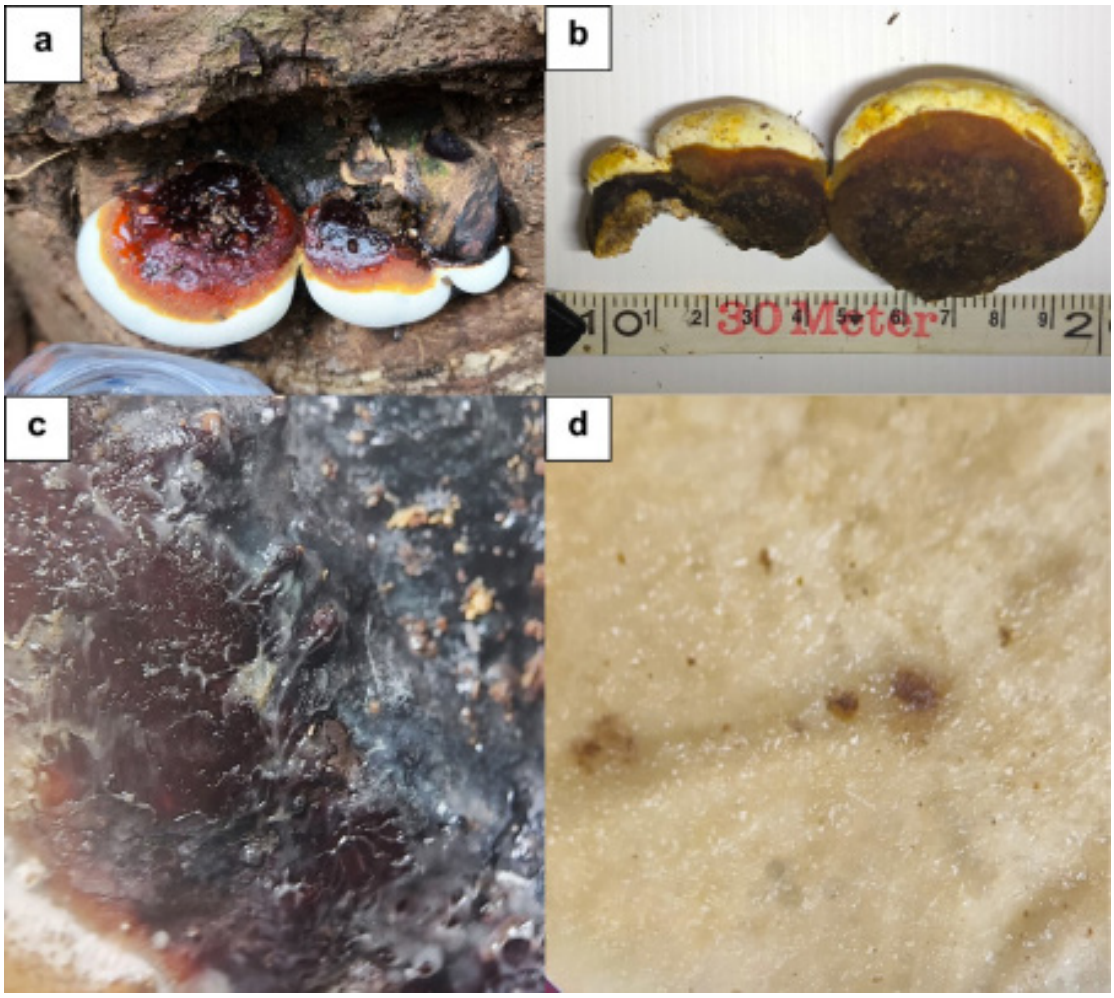

Figure 2 . Macroscopic characteristics of *Ganoderma* sp.1. (a) fruiting body in habitat, (b) fruiting body size, (c) upper surface of the fruiting body, (d) lower surface of the fruiting body.

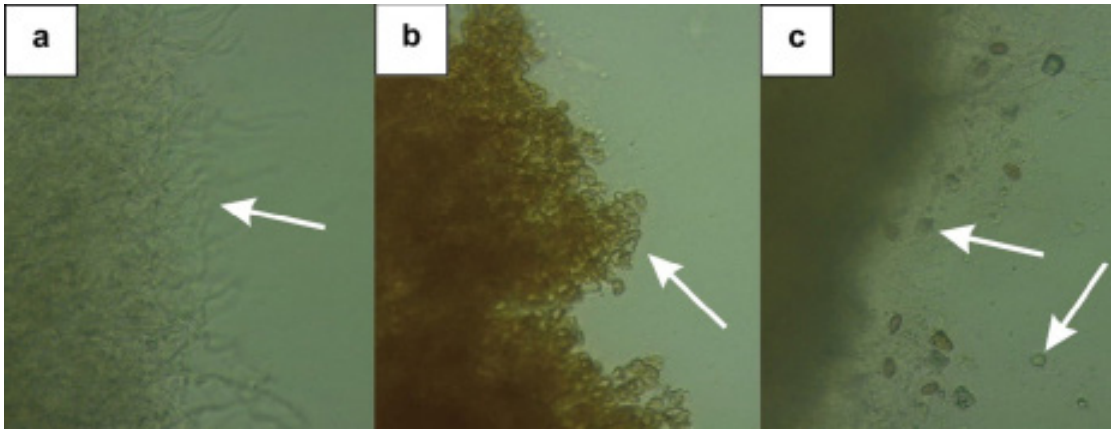

Figure 3. Microscopic characteristics of *Ganoderma* sp.1 (40x10 magnification). (a) hyphae, (b) pileipellis, (c) spores (vertical arow) and oxalate crystals (horizontal arow)

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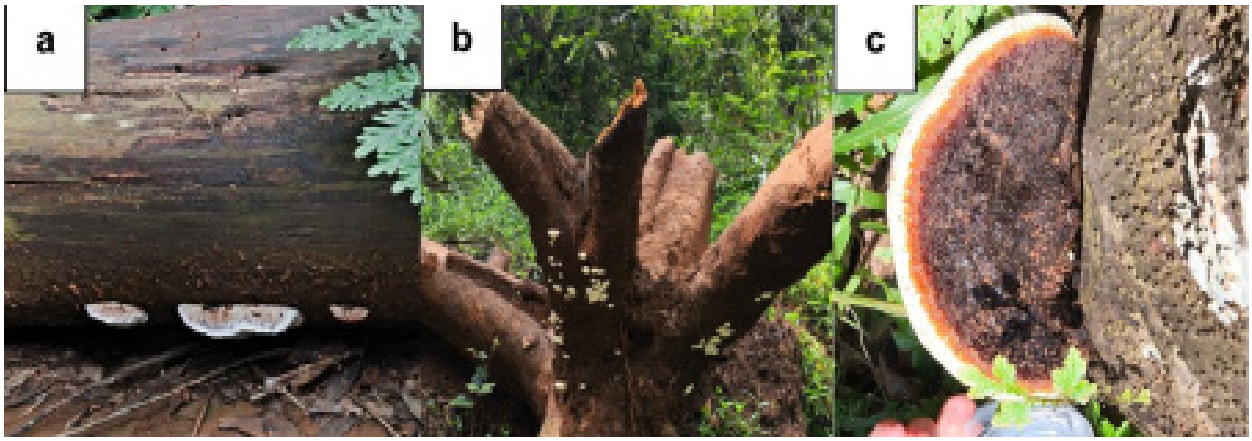

Figure 4. *Ganoderma* sp.1 colonization location on *Agathis* sp. (a) stem, (b) root, (c) basidioma attachment to substrate

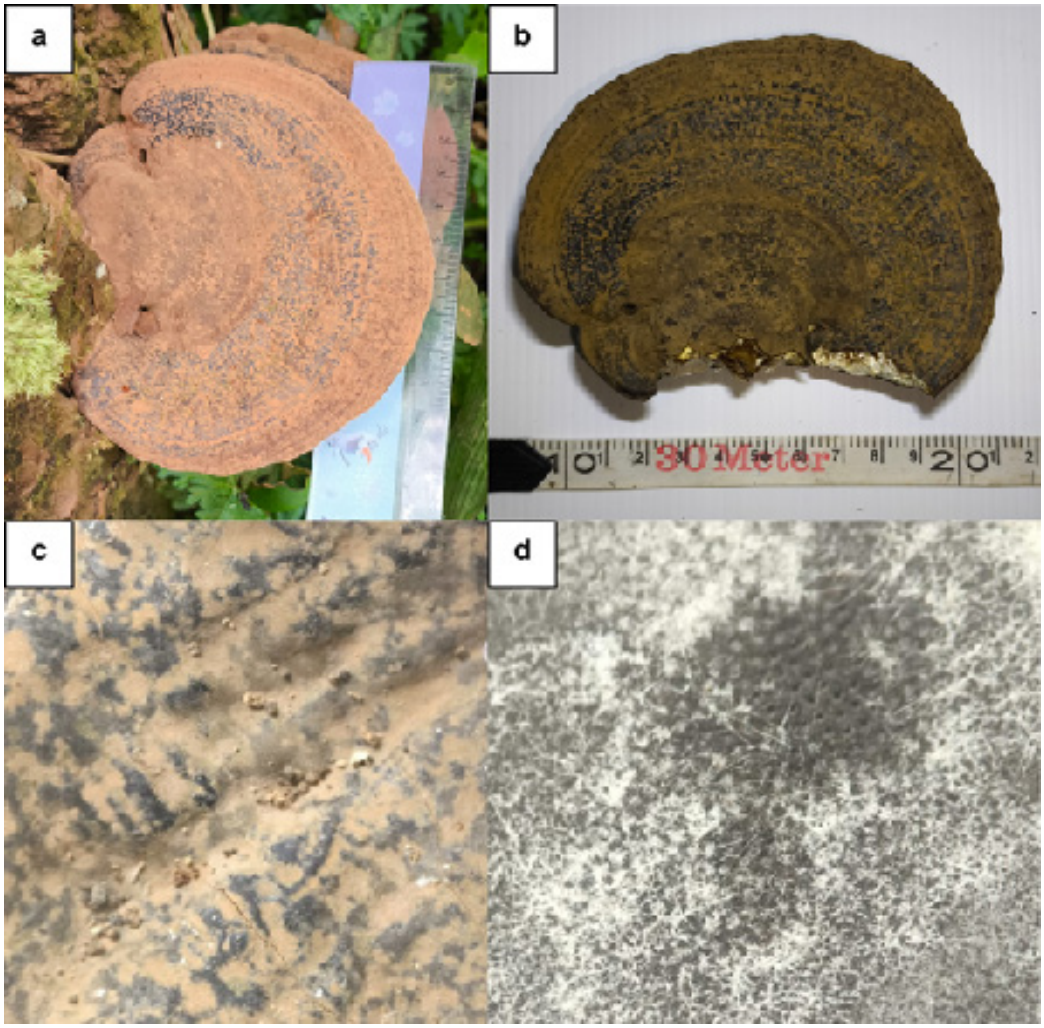

Figure 5. Macroscopic characteristics of *Ganoderma* sp.2. (a) fruit body in habitat, (b) size of the fruit body, (c) upper surface of the fruiting body, (d) surface underneath fruiting body.

Ganoderma sp.1 (Figure 4c) tends to adhere to *Agathis* sp. (Figure 4a-b) trees under various conditions, whether the trees are dead or alive. The highest settlement values in the host are not significantly different between dead roots and the base of living stems. These insignificant values suggest that *Ganoderma* infections frequently occur in the underground parts of the plant. According to Herliyana (2012), *Ganoderma* infections are primarily caused by two factors: irrigation and root contact with fungi. The *Agathis* sp. trees at the sampling site are used as a valuable source of charcoal. Harvesting charcoal from *Agathis* sp. requires creating openings that make the trees susceptible to *Ganoderma* sp.1. Additionally, root contact can also lead to infections. The larger the infected tree, the greater the likelihood of it spreading the infection to neighbouring trees.

***Ganoderma* sp.2**

Ganoderma sp.2 has a hard basidioma with a half-circular shape (Figure 5a-b), brown to black colour. Basidiomata can be found colonized both dead wood and living tree. *Ganoderma* sp.2 has a smooth, non-porous upper surface (Figure 5c). The lower surface (Figure 5d) of the fruiting body is porous with fine hyphal fibers that are black and white. Hyphae on the upper surface of *Ganoderma* sp.2 are septate (Figure 6a). The spores of this species are oval shape (Figure 6b).

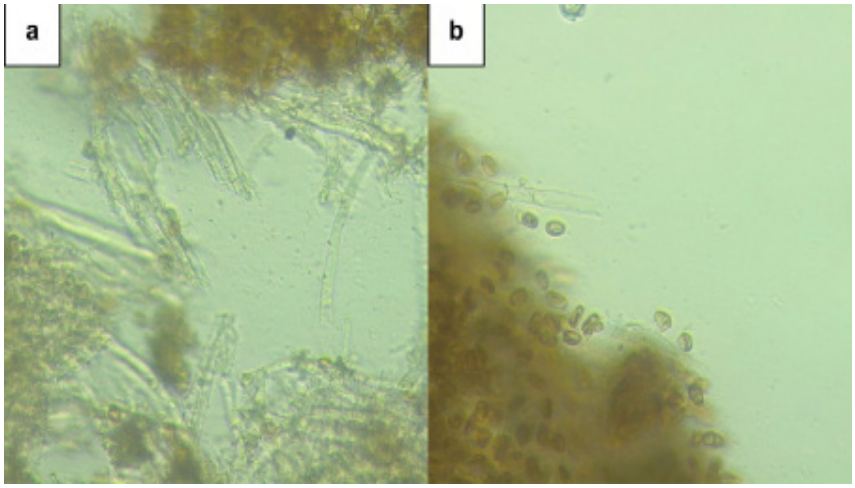

Figure 6. Microscopic characteristics of *Ganoderma* sp.2 (40x10 magnification). (a) hyphae, (b) spores.

Ganoderma sp.2 (Figure 7b) attach to various tree (Figure 7a, 7b) species, including *Agathis* sp., *Pinus merkusii*, and *Schima wallichii*. This fungus infects both living and dead trees. *Ganoderma* sp.2 shows a slight preference for *S. wallichii*, with a higher number of infections than other hosts. It prefers substrates that do not emit resin, as evidenced by its preference for *S. wallichii* over the resin-emitting *Agathis* sp. and *P. merkusii*. The infection sites of *Ganoderma* sp.2 are often wounds created for resin production, which allow the fungus to enter through open tissue. There are fewer instances of *Ganoderma* sp.2 on dead *Agathis* sp. trunks compared to dead *S. wallichii* trunks, suggesting a preference for *S. wallichii.* However, the current data on *Ganoderma* sp.2 infections is limited, which the estimation preference is still not serving any strong evidence in the current study.

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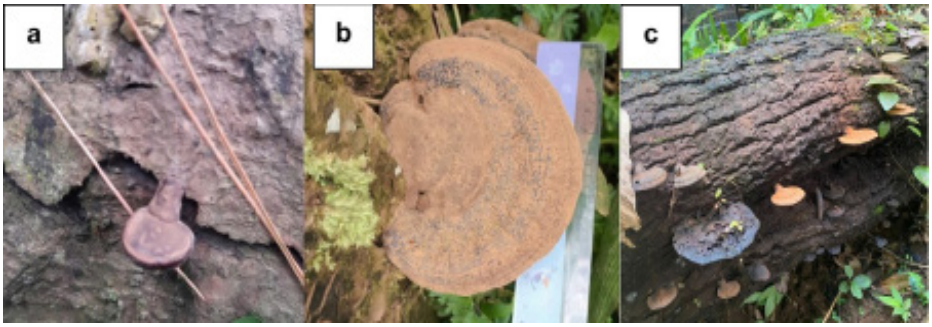

Figure 7. *Ganoderma* sp.2 colonization location on various hosts. (a) *Agathis* sp. dead trunk, (b) *Pinus merkusii* base trunk, (c) *Schima wallichii* dead trunk*Pinus merkusii* base trunk, (c) *Schima wallichii* dead trunk

***Ganoderma* sp.3**

Ganoderma sp.3posed a hard fruiting body with a woody skin texture, semicircular in shape, light beige colour on the outer circle and has a greenish ash color on the innermost circle (Figure 8a-b). The lower surface of the fruiting body is dark brown to black in color. This fungus was observed attached to a substrate in the form of a living tree with deciduous leaves. The basidioma was observed growing in colonies on wooden trunks.

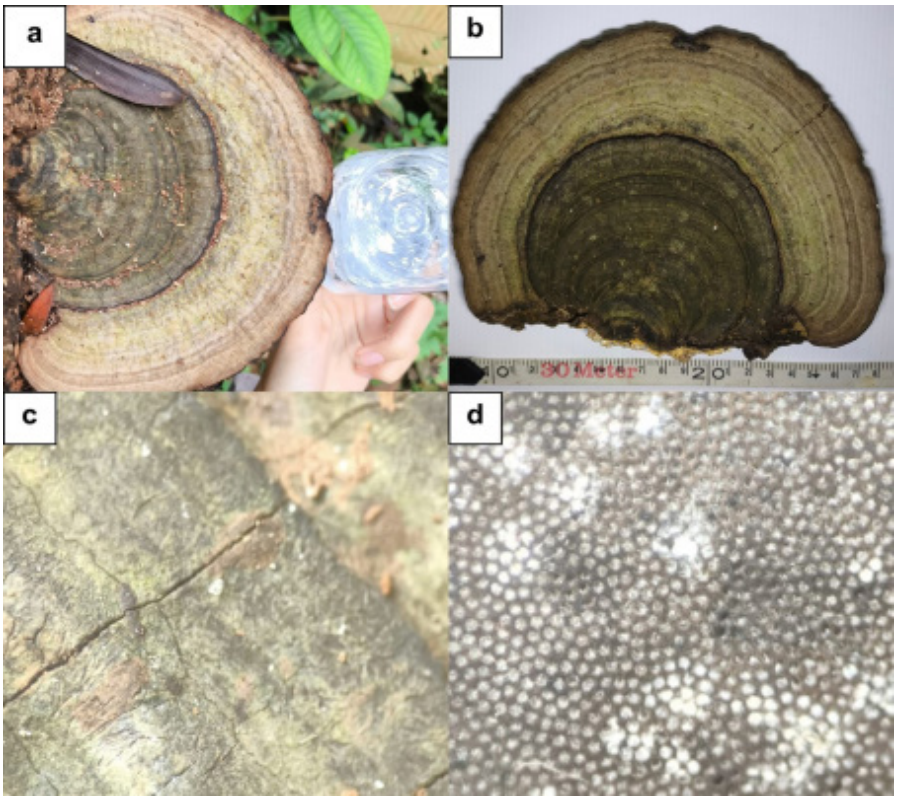

Figure 8. Macroscopic characteristics of *Ganoderma* sp.3. (a) fruiting body in habitat, (b) size of the fruiting body, (c) upper surface of the fruiting body, (d) surface underneath fruiting body

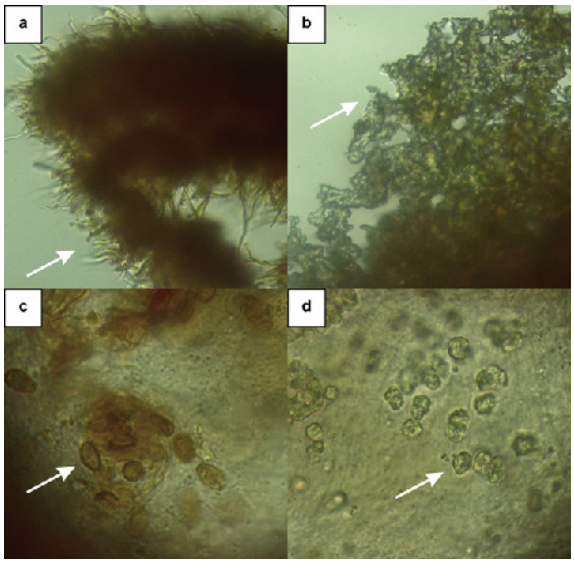

Figure 9. Microscopic characteristics of *Ganoderma* sp.3 (40x10 magnification). (a) hyphae, (b) pileipelis, (c) spores, (d) oxalate crystals

Ganoderma sp.3 has a rough upper surface texture of the fruiting body and has a woody texture (Figure 8b). The lower surface (Figure 8c) of *Ganoderma* sp.3 is porous and with fine hyphal fibers in black and white. Pileipellis composed of hyphae with irregular shapes (Figure 9a), spores oval (Figure 9c), and abundance oxalate crystals (Figure 9b and d).

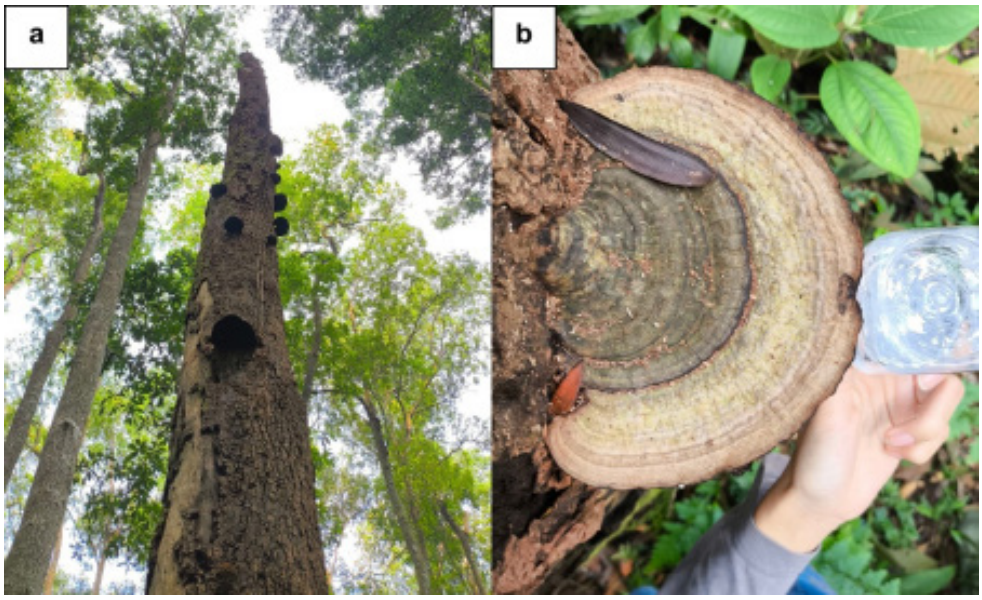

Figure 10. *Ganoderma* sp.3 colonization location on *Schima wallichii.* (a), host with basidiomata, (b) upper side of basidioma.

Ganoderma sp.3 was only found on one tree, *Schima wallichii* (Figure 10a). Its attachment differs from that of the other *Ganoderma* species observed, which tend to attach to the base of the trunk (Figure 10b). However, *Ganoderma* sp.3 attached to the trunk, even at considerable heights. Infection by *Ganoderma* sp.3 can occur through airborne spores, which spread with the wind and attach to trees with trunk wounds, leading to infection (Herliyana, 2012). The preference of *Ganoderma* sp.3 for specific hosts cannot be determined with certainty due to the limited data available in the current study.

Ganoderma interaction with ambient insects

The interaction of insects around *Ganoderma* was observed on four different basidiomata. Various insects, including beetles, ants, and larvae, were encountered on *Ganoderma*. These interactions generally exhibit a symbiotic relationship of mutualism, where both the insects and the fungus benefit. For instance, insects may help in spore dispersal (Syarif et al., 2024) while gaining shelter and food from the fungus. However, instances of commensalism were also noted, where insects benefit from the fungus without affecting it. Insects that interact with *Ganoderma* tend to colonize and use it as a shelter, taking advantage of the structure and resources provided by the fungus. This relationship highlights the ecological significance of Ganoderma as a habitat and resource for various insect species.

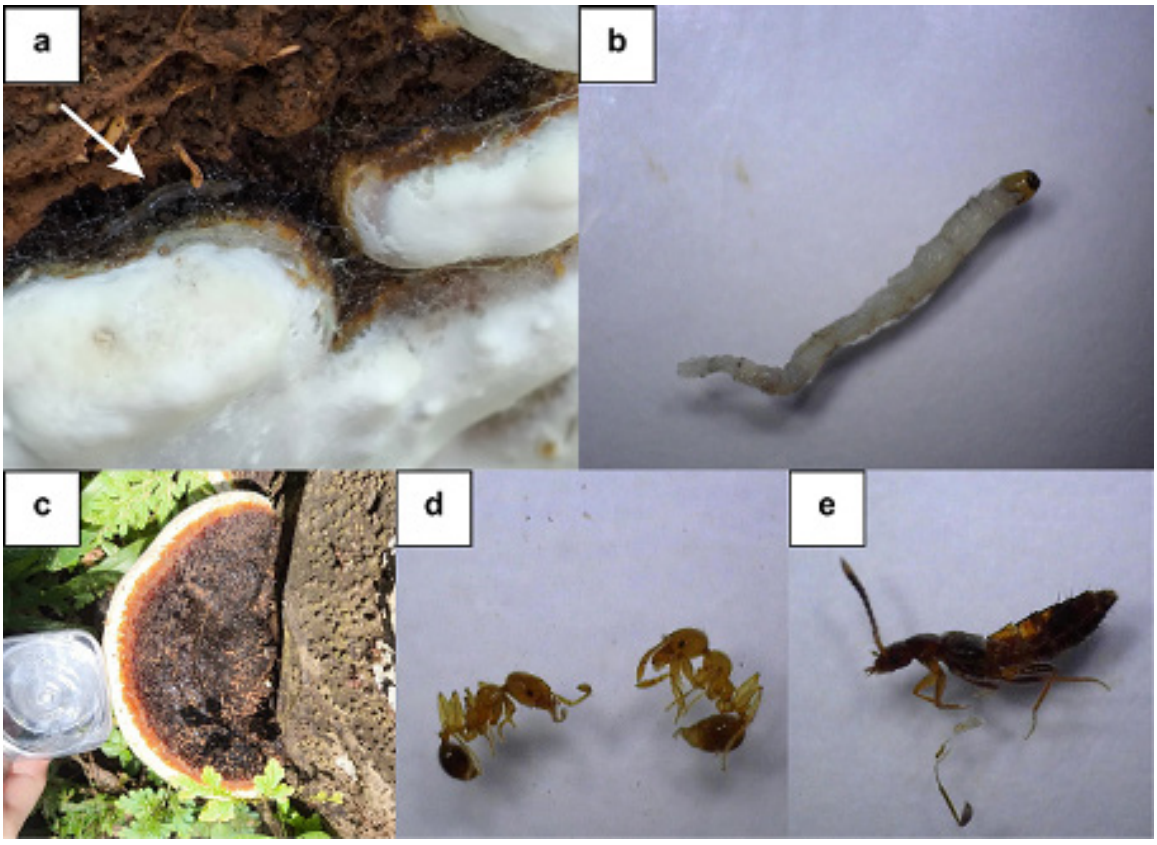

Figure 11. Documentation of insect visitors on the fruiting body of *Ganoderma* sp.1. (a) Larvae on basidioma, (b) Morphology of larvae of diptera (c) Insects on basidioma (d) Morphology of *Trichomyrmex destructor* under 39x magnification stereo microscope (e) Morphology of *Meronera venustula* under 42.6x magnification stereo microscope.

Insect interaction with *Ganoderma* sp.1

Insect interaction with *Ganoderma* sp.1 was observed with insect larvae attached between the primordium hyphae (Figure 11a). Additional evidence included two small insects on different specimens (Figure 11c-e). Larvae were found in the fruiting body primordia, on the roots of dead trees, with about 10-15 individuals visible (Figure 11b). These larvae, approximately 0.5-1 cm in size, had transparent white bodies and brown heads. They belong to the Diptera group which usually utilize the resources of the fungus (Graf-Peters et al., 2011). This interaction suggests that *Ganoderma* provides suitable conditions for larval growth, such as high humidity and fine hyphal structures that serve as a food source and offer protection from predators. Research by Hathaway (2018) indicates that insects can use the fruiting bodies of fungi to raise their offspring. In return, *Ganoderma* benefits from spore dispersal by insects, making the interaction a form of symbiotic mutualism.

Insect interaction with *Ganoderma* sp.2

Ganoderma sp.2 was observed interacting with *Novius* sp. beetles (Figure 12a). These beetles were seen traversing both the top and bottom surfaces of *Ganoderma* sp.2. Some beetles were found entering and exiting the mushroom fruiting body, as well as moving between the tree and *Ganoderma* sp.2. Three to five individuals of *Novius* sp. were observed on the upper and lower surfaces of fruiting bodies. These beetles are small to medium-sized, measuring 2.5-4 millimetres. Morphologically, *Novius* sp. has a half-round body, with the dorsal part being brownish-red and covered with short hairs (Figure 12b-c). They may have spots or be spotless and possess short antennae with eight segments. Due to their small size, interactions such as mycophagy are challenging to determine. However, it is suspected that *Novius* sp. uses *Ganoderma* sp.2 as a shelter. The fungus can serve as a temporary refuge for insects, protecting them from high temperatures. This interaction can be described as symbiotic

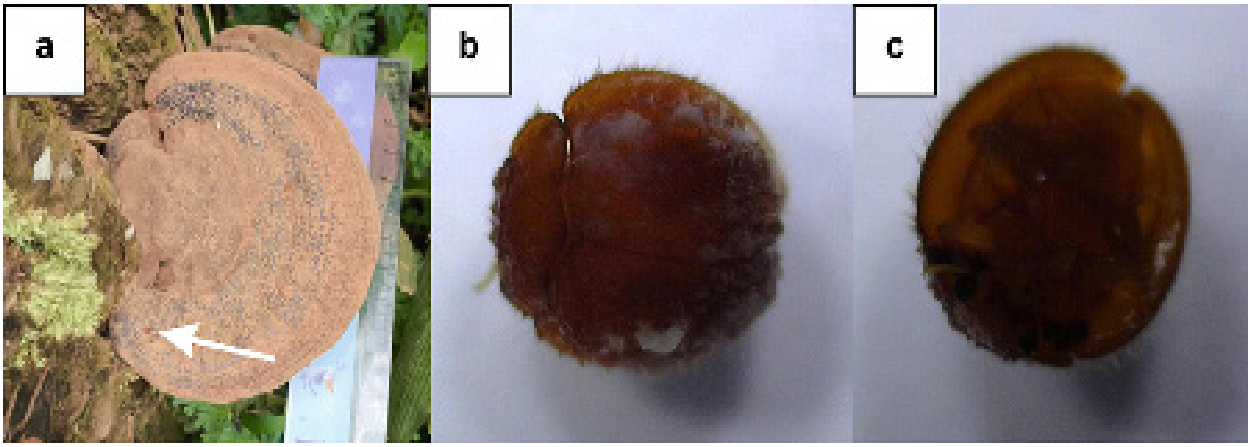

Figure 12. Documentation of insect visitors on the fruiting bodies of *Ganoderma* sp.2. (a) Locations where insects were found, (b) dorsal morphology of *Novius* sp. under 51x magnification of stereo microscope, (c) ventral morphology of *Novius* sp. under 48.8x magnification stereo microscope

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Insect interaction with *Ganoderma* sp. 3

The interaction between insects and *Ganoderma* sp.3 was observed with the discovery of the beetle *Eumorphus marginatus* (Figure 13a). This beetle was found attached to the hymenium. The beetles attach not only to a single fruiting body but to almost all fruiting bodies growing on *S. wallichii*. Each fruiting body hosting approximately 7-15 individuals, depending on the surface area of the hymenium. *E. marginatus* has a body size of about 0.5 to 1.5 cm, with elytra (hardened beetle wings) that have wide lateral flat edges (Figure 13b-c). The elytra are ovoid with yellow spots, consisting of two pairs spaced apart. The beetles use basidioma as a shelter. The strong and hard fruiting body of the fungus can serve as a simple refuge for other insects (Santamaria et a., 2023). This interaction is mutually beneficial, as the beetles help spread *Ganoderma* sp.3 spores. The hymenium is a part that contains an abundant number of spores. The attachment of *E. marginatus* to the hymenium allows *Ganoderma* spores to adhere to the beetle's body, facilitating spore dispersal. There is also the possibility of hymenium consumption by *E. marginatus* (Lunde et al., 2023). Beetles are known to spend their entire life cycle around the fruiting bodies of fungi, with larvae feeding on wood or hyphae and adults consuming fungal hymenium (Schigel 2004; Schigel 2006). However, mycophagy is difficult to observe in the field, so this behaviour could not be confirmed in this observation.

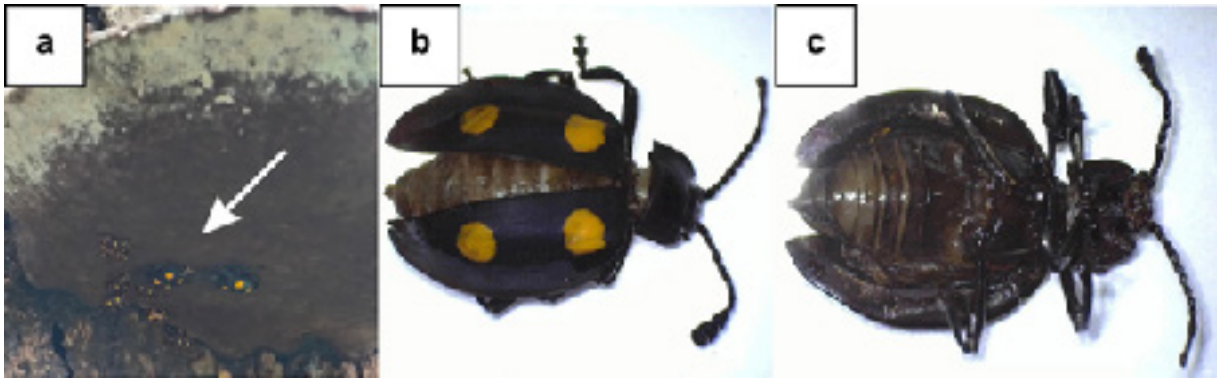

Figure 13. Documentation of insect visitors on the fruiting bodies of *Ganoderma* sp.3. (a) Locations where insects were found, (a) dorsal morphology of *Eumorphus marginatus* under 10.3x magnification of stereo microscope, (c) ventral morphology of *Eumorphus marginatus* under 10.3x magnification of stereo microscope

CONCLUSION

Ganoderma spp. was found attached to the hosts of *Agathis* sp., *Schima wallichii,* and *Pinus merkusii*. The preference of the *Ganoderma* to stick to a tree in the Gunung Walat Educational Forest is to stick on the tree of *Agathis* sp. The interaction of the *Ganoderma* with insects has also been found. *Ganoderma* sp.1 was found to interact with larvae of insects from the Diptera group as a breeding site, and two other insects, *Trichomyrmex destructor* and *Meronera venustula,* were able to use fruit body for the shade. *Ganoderma* sp.2 has been found to interact with *Novius* sp. *Novius* sp. has been known to make *Ganoderma* as a shelter. Meanwhile, *Ganoderma* sp.3 has been found to interact with *Eumorphus marginatus* which makes the hymenium of *Ganoderma* sp.3 a

a nesting place. The entire interaction that occurs belongs to the symbiosis of mutualism, because in addition to *Ganoderma* can provide a source of nutrition and shadow against some insects, *Ganoderma* also benefits from the existence of insects as spore-proliferating agents.

AUTHOR CONTRIBUTION

M.T.M, C.C and N.H.A conducted the research and article writing. I.P.P designed the research and edited the final manuscript.

ACKNOWLEDGMENTS

We thank Department of Biology, Faculty of Mathematics and Natural Sciences, IPB University and *Gunung Walat* Educational Forest for all support.

CONFLICT OF INTEREST

We declare no conflict of interest.

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