Vol. 10 No. 1September 2026

ISSN : 2597 - 8713 (ONLINE)
ISSN : 2598 - 5167 (PRINT)
Agricultural Science

AGRICULTURAL SCIENCE
Journal Of Agricultural Science And Agriculture Engineering
Faculty of Agriculture, Merdeka University Surabaya,Indonesia
Available on :
https://agriculturalscience.unmerbaya.ac.id/index.php/agriscience/index

Diversity of Arbuscular Mycorrhizal Fungi In Palm Habitats of *Pigafetta elata* Lore Lindu National Park

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Article History: Received: April 14, 2026; Accepted: June 05, 2026

ABSTRACT

This study aimed to describe the species of arbuscular mycorrhizal fungi (AMF), analyze spore density, assess the level of AMF colonization in the roots of Pigafetta elata, and evaluate the physical and chemical properties of soils within its habitat.The study was conducted from August to October 2025. Soil and root samples of Pigafetta elata were collected from its habitats in Puroo Village, Lindu District, Sigi Regency, and Sedoa Village, North Lore District, Poso Regency. Soil samples were analyzed to identify AMF morphospecies and determine spore density, while root samples were analyzed to determine the percentage of root colonization. These analyses were carried out at the Forest Biotechnology Laboratory, Bogor Agricultural University (IPB University), Bogor, West Java. Analyses of soil physical and chemical properties were conducted at the Soil Science Laboratory, Faculty of Agriculture, Tadulako University, Palu.The results showed that in Puroo Village, three AMF morphospecies belonging to two genera (Acaulospora and Glomus) were identified, with a spore density of 5 spores per 20 g of soil and a root colonization rate of 49.56%. In contrast, in Sedoa Village, seventeen morphospecies belonging to three genera (Acaulospora, Glomus, and Gigaspora) were identified, with a spore density of 47 spores per 20 g of soil and a colonization rate of 45.84%. These differences were associated with edaphic conditions: Puroo had a near-neutral soil pH (6.30), high organic carbon content (4.15%), and good porosity (55.86%), whereas Sedoa had acidic soil conditions (pH 4.48), moderate organic carbon content (2.16%), and lower porosity (45.84%). This study revealed an ecological trade-off within AMF communities. In habitats with favorable soil conditions (Puroo), AMF allocated more energy to root colonization. Conversely, in environmentally stressed habitats (Sedoa), AMF produced a greater number of spores as a survival strategy. These findings provide baseline information for the conservation of Pigafetta elata and support the utilization of AMF as a biological agent in ecosystem restoration efforts

Keywords : Pigafetta elata, Arbuscular Mycorrhizal Fungi (AMF), Lore Lindu National Park, spore density, colonization, soil properties.

1. INTRODUCTION

Sulawesi is one of the regions in Indonesia known for having a very high level of plant endemism, particularly for the palm family (Arecaceae). Based on inventory results, it is estimated that there are around 51 endemic palm species distributed across Sulawesi, one of the most distinctive of which is *Pigafetta elata* (Aras et al., 2017). This palm is known locally by various names such as *wanga* or *pangi*, and has a characteristic habitat with a slender, towering trunk and

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ISSN : 2598 - 5167 (PRINT)
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pinnately arranged leaves. Ecologically, *Pigafetta elata* plays an important role in maintaining the stability of tropical forest ecosystems, including providing canopy cover, controlling soil erosion, and serving as a food source and habitat for various wildlife species (Yuzammi, 2002).

However, in recent decades, the population of *Pigafetta elata* in its natural habitat has experienced a significant decline. The main causes are various community activities around its habitat, such as the conversion of forest land into plantation areas, illegal logging, and so forth, which disrupt the natural regeneration of this palm. This condition is exacerbated by the low success rate of natural regeneration of *Pigafetta elata* because its seeds require specific environmental conditions to germinate (Aras et al., 2017). Therefore, conservation and restoration measures based on comprehensive scientific studies are urgently needed.

One potential approach in land rehabilitation and endemic plant conservation efforts is the utilization of soil microbes, particularly Arbuscular Mycorrhizal Fungi (AMF). AMF are a group of fungi from the phylum Glomeromycota that form obligate mutualistic symbioses with the roots of approximately 80–90% of terrestrial plants. The main characteristics of AMF include their ability to form extensive external hyphal structures in the soil, as well as internal hyphae, arbuscules, and vesicles within the root cortex cells. The arbuscule is the primary site of nutrient exchange between the fungus and the host plant, where the fungus provides nutrients (especially phosphorus) and water, while the host plant provides carbon from photosynthesis (Rini et al., 2021).

The benefits of AMF symbiosis for host plants have been widely reported. AMF have been shown to significantly increase the efficiency of nutrient uptake, especially phosphorus (P), which is relatively immobile in the soil, as well as nitrogen (N), potassium (K), and other micronutrients (Sun et al., 2022). Additionally, AMF enhance plant resistance to abiotic stresses such as drought, high salinity, and extreme temperatures, and also increase resistance to soil-borne pathogens (Aurum et al., 2020). AMF also play a role in improving soil structure through the production of glomalin, a glycoprotein that helps bind soil particles into stable aggregates.

According to (Maulana et al., 2017), the use of mycorrhizae can support plant growth through various adaptive mechanisms and enable plants to survive on degraded land, thus AMF have a very important role in the sustainability of tropical forests. Furthermore, AMF are also known to support plant growth under high soil salinity conditions (He et al., 2020) as well as in environments exposed to heavy metals (Husna et al., 2021).

Therefore, arbuscular mycorrhizal fungi are key components of the soil microbial community that play an important role in the formation of healthy soils and support the successful

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rehabilitation of forest ecosystems and the sustainable conservation of endemic plants (Bender et al., 2016). Information regarding the influence of habitat and elevation variation on the presence of AMF in Sulawesi's endemic palms is still very limited. Although research on arbuscular mycorrhizal fungi (AMF) in various palm species has been conducted extensively, information on AMF communities associated with the endemic palm *Pigafetta elata* in its natural habitat is still very scarce. To date, no studies have been found that analyze AMF diversity, spore density, root colonization levels, and their relationship with soil properties and altitude in the habitat of *Pigafetta elata* in Lore Lindu National Park.

This study aims to analyze the diversity of arbuscular mycorrhizal fungi associated with *Pigafetta elata* in two habitats in Lore Lindu National Park, as well as to evaluate the relationships between AMF diversity, root colonization, soil properties, and vegetation composition. The results of this study are expected to provide baseline information to support the conservation and sustainable habitat management of Sulawesi's endemic plants.

2. MATERIALS AND METHODS

Time and Location

This research was conducted from August to November 2025 in two natural habitats of the Wanga Palm (*Pigafetta elata*) located within the Lore Lindu National Park area, Central Sulawesi, namely: Puroo Village, Lindu District, Sigi Regency at an elevation of approximately 1000 m above sea level, and Sedoa Village, North Lore District, Poso Regency at an elevation of 1048–1500 m above sea level. The sampling locations are presented in Figure 1. Analysis of arbuscular mycorrhizal fungi (AMF) and root colonization was carried out at the Laboratory of the Biotechnology Center, Bogor Agricultural University (IPB), while analysis of soil physical and chemical properties was conducted at the Soil Science Laboratory, Faculty of Agriculture, Tadulako University.

Figure 1. Map of Soil and Root Sampling Locations in Both Habitats of the Palm *Pigafetta elata* in Lore Lindu National Park

Vol. 10 No. 1September 2026

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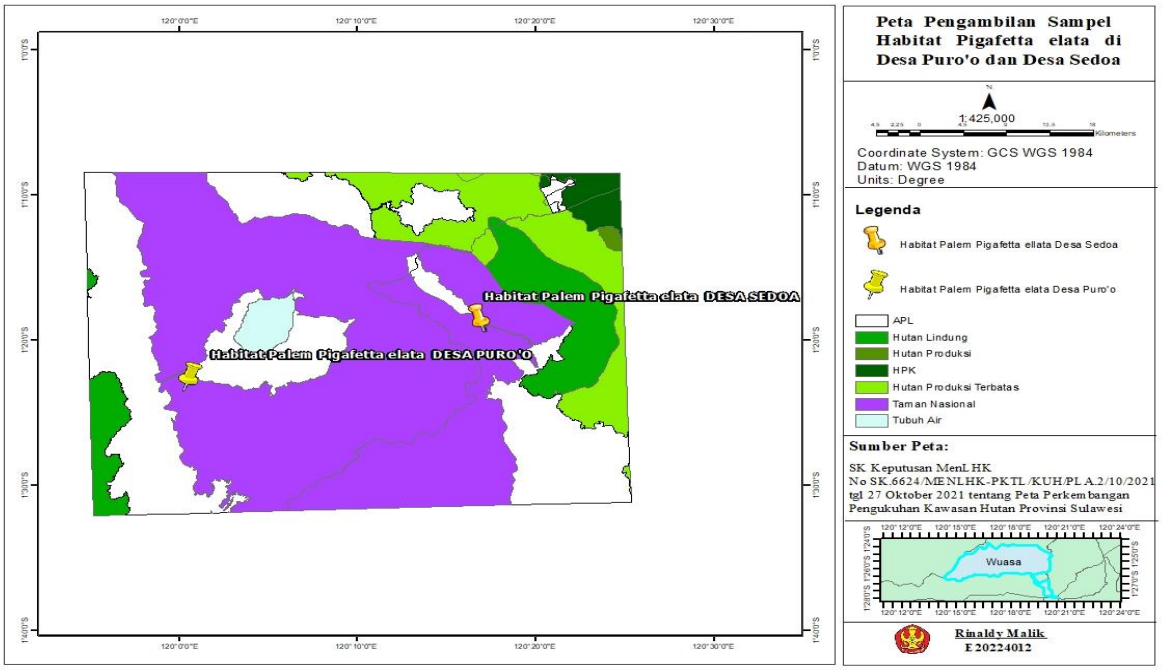

Equipment and Materials

The equipment used in this study included field and laboratory apparatus. Field equipment consisted of a hoe, shovel, knife, scissors, tweezers, measuring tape, raffia string, plastic bags, paper labels, ring sampler, GPS, digital camera, writing instruments, and a portable analytical balance. Laboratory equipment for AMF isolation included a set of sieves (250 µm, 125 µm, 60 µm), centrifuge, test tubes, petri dishes, measuring cylinder, plastic funnel, and a binocular light microscope (40–1000× magnification). Equipment for soil analysis included an analytical balance, 105°C oven, pH meter, burette, volumetric flask, Erlenmeyer flask, and other glassware.

The materials used consisted of soil and root samples from both research locations. Chemical materials for AMF isolation and identification included PVLG (Polyvinyl Lacto Glycerol) solution, distilled water, 40% sugar solution, and 50% alcohol. Materials for root staining included 2.5% KOH, 1% HCl, 0.05% trypan blue solution, and 50% glycerol solution.

Soil and Root Sampling

Sampling was conducted using a purposive sampling method based on the presence of *Pigafetta elata* populations in each habitat. At each location, five replicate observation points were established to represent local habitat conditions. The determination of observation points followed the ICRAF plot method modified according to field conditions.

Soil samples were taken from the rhizosphere of *P. elata* plants at a depth of 0–20 cm. At each replicate point, five soil subsamples of 200 g each were collected from around the root

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system. All subsamples were then homogeneously mixed into one composite sample weighing approximately 1 kg. Soil samples were placed into labeled plastic bags and stored at room temperature before laboratory analysis.

Root samples were taken from fine lateral roots with a diameter of less than 1 mm that were still actively absorbing nutrients. Root collection was carried out by tracing lateral roots to the root tips and digging carefully to avoid tissue damage. A total of 5–10 g of roots was collected at each observation point, then stored in sample bottles containing 50% alcohol solution until AMF colonization analysis was performed.

Spore Isolation and Identification

Spore isolation was performed using the pour and wet-sieving method and centrifugation modified from (Brundet et al., 1996).

A 100-gram soil sample was suspended in one liter of sterile water and sieved stepwise using sieves of 500 µm, 250 µm, 90 µm, and 63 µm. The residue from the 250–63 µm sieve was placed into centrifuge tubes, then centrifuged for five minutes at 2000 rpm. The pellet was resuspended in 50% sucrose solution and centrifuged for two minutes. The supernatant containing spores was re-sieved, rinsed with water, and observed under a microscope at 40–100× magnification. The isolated spores were mounted in PVLG and Melzer's solution for morphological identification based on color, size, shape, ornamentation, and hyphal structure using guidelines from (INVAM (2020).

Root Colonization Observation

Root colonization observation was performed using a root staining method modified from (Brundet et al., 1996). Root segments of approximately 1 cm in length were cleared using 2.5% KOH solution, then acidified with 1% HCl and stained using 0.05% trypan blue solution. Observation was conducted under a microscope at 100–400× magnification. AMF colonization was determined based on the presence of mycorrhizal structures such as internal hyphae, arbuscules, vesicles, and coiled hyphae within the root tissue.

The percentage of root colonization was calculated using the formula according to Hadianur et al., (2016):

$$\text{Colonization} = \frac{\Sigma \text{ Colonized fields of view}}{\Sigma \text{ Total fields of view}} \times 100\%$$

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Table 1. Criteria for Mycorrhizal Colonization Degree

No.	Colonization Degree (%)	Criteria
1.	0-5	Very Low
2.	>5-25	Low
3.	>25-50	Moderate
4.	>50-75	High
5.	>75-100	Very High

Analysis of Soil Physical and Chemical Properties

Soil property analysis was conducted to support the interpretation of AMF presence in *P. elata* habitat. The soil chemical parameters analyzed included pH H_2O, pH KCl, organic C, total N, available P, available K, and cation exchange capacity (CEC). Soil physical parameters included moisture content, soil texture, bulk density, porosity, and permeability.

Data Analysis

Arbuscular mycorrhizal fungi (AMF) data were analyzed descriptively based on the number of morphospecies, genera, spore morphological characteristics, spore density, and root colonization levels found in the habitat of *Pigafetta elata*. Morphospecies identification was carried out based on spore morphological characteristics including shape, size, color, spore wall ornamentation, and hyphal structure.

$$\text{Spore density} = \frac{\text{Number of spores}}{\text{20 g of soil}}$$

Spore Density = Number of Spores / 20 Grams of Soil

The percentage of root colonization was calculated based on the number of fields of view showing the presence of AMF structures compared to the total number of fields of view observed. The observation results are presented in the form of tables, figures, and descriptive explanations to describe the diversity of AMF associated with *Pigafetta elata* in the Lore Lindu National Park area.

3. RESULT AND DISCUSSION

Diversity of Arbuscular Mycorrhizal Fungi Species

The results showed that 3 morphospecies belonging to 2 genera of AMF were found in the habitat of the *Pigafetta elata* palm in Puroo Village. Furthermore, 17 morphospecies from 3 genera of AMF were found in the habitat of *Pigafetta elata* in Sedoa Village, as presented in Table 2 below.

ISSN : 2597 - 8713 (ONLINE)
ISSN : 2598 - 5167 (PRINT)
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Table 2. Characteristics of AMF in two habitats of *Pigafetta elata*

AMF Species	Description			
	Color	Shape	Size	Location
Acaulospora sp1	Yellow	Round	140 µm	Village Puroo
Glomus sp1	Clear/transparent	Round	120 µm	Village Puroo
Glomus sp2	Yellow	Oblong	80-90 x 130-160 µm	Village Puroo
Acaulospora sp2	Clear/transparent	Round	120 µm	Village Sedoa
Acaulospora sp3	Clear/transparent	Round	180 µm	Village Sedoa
Acaulospora sp4	Yellow	Round	110-120 µm	Village Sedoa
Acaulospora sp5	Clear/transparent	Round	220 µm	Village Sedoa
Acaulospora sp6	Clear/transparent	Round	260 µm	Village Sedoa
Acaulospora sp7	Reddish-brown	Round	130 µm	Village Sedoa
Glomus sp3	Clear/transparent	Round	180 µm	Village Sedoa
Glomus sp4	Yellow	Round	130 µm	Village Sedoa
Glomus sp5	Yellow	Round	250 µm	Village Sedoa
Glomus sp6	Yellowish	Round	130-140 µm	Village Sedoa
Glomus sp7	Yellow	Oblong	100-130 µm	Village Sedoa
Glomus sp8	Blackish	Round	100 µm	Village Sedoa
Glomus sp9	Brown	Round	120 µm	Village Sedoa
Glomus sp10	Yellow	Round	120-140 µm	Village Sedoa
Glomus sp11	Reddish-brown	Round	140-170 x 80 µm	Village Sedoa
Gigaspora sp1	Yellowish	Round	230-270 µm	Village Sedoa
Gigaspora sp2	Clear/transparent	Round	280-400 µm	Village Sedoa

Based on the identification results of spores obtained from two different locations, a fairly high level of diversity was observed in terms of shape, type, size, and number of spores found. The size of mycorrhizal spores showed considerable variation among samples. The results also revealed that the spores exhibited striking color differences, including clear/transparent, yellow, reddish-brown, blackish, brown, and reddish-brown. Among these various colors, clear/transparent and yellow spores appeared to dominate. This diversity indicates that environmental conditions at each location influence the morphological characteristics of the spores formed.

According to the observation results, eleven *Glomus* species were identified, distinguished based on variations in spore size and color. *Glomus* sp. is a mycorrhizal genus in the family Glomeraceae and is known to have the highest level of diversity compared to other mycorrhizal genera. *Glomus* sp. is also quite abundant in the environment, as many *Glomus* spores were found in the palm habitat. This genus has several characteristic features, such as spores appearing singly or in pairs at the tips of non-gametangial hyphae, where the hyphae do not transform into specialized structures such as carpus spores. These characteristics make *Glomus* sp. an important group in the formation of arbuscular mycorrhizal associations, which play a major role in enhancing the ability of plants to absorb nutrients (Sarah & Rendo, 2023). According to INVAM

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(2020), this genus has the highest number of species compared to other genera in the existing mycorrhizal groups.

The genus *Acaulospora* has spores that are generally round to oblong-round. This genus exhibits several distinctive features, including two- to three-layered spore walls, spores formed on the side of the spore sac neck, and round or elliptical shape. Spore colors can be clear/transparent, yellow, and reddish-brown, with sizes ranging from 110–260 μm. The spore-producing saccule structure develops blastically from the hyphal tip. After the saccule is fully formed, the spore begins to emerge from the subtending hypha, an area referred to as the "saccule neck." When the spore reaches maturity, the saccule typically loses its contents and then detaches, so that at maturity it is often no longer attached to the spore (INVAM (20). This genus is also known to have better adaptability to soils with pH below 5 to neutral, or in environments with acidic tendencies.

The genus *Gigaspora* was found at the research location in Sedoa Village, yellowish and clear/transparent in color, and had a larger size than the other two genera. According to Miska et al., (2016), *Gigaspora* sp. is a mycorrhizal group from the family Gigasporaceae. This genus has several characteristic features, such as the formation of single spores in the soil, the absence of an inner spore wall layer, the presence of a bulbous suspensor, and spore shapes that are generally globose or sub-globose.

Vol. 10 No. 1September 2026

ISSN : 2597 - 8713 (ONLINE)
ISSN : 2598 - 5167 (PRINT)
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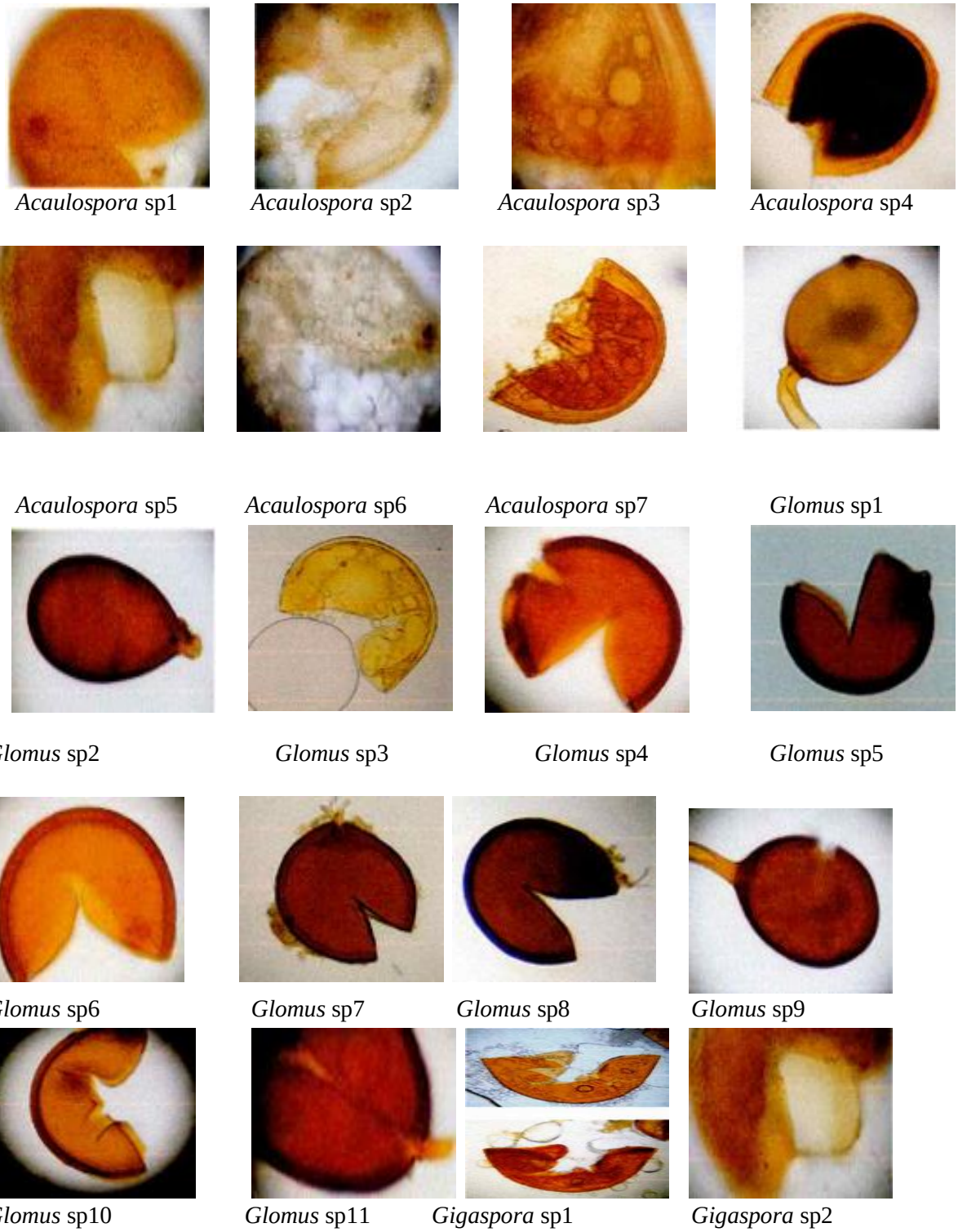

Acaulospora sp1 | *Acaulospora* sp2 | *Acaulospora* sp3 | *Acaulospora* sp4

Acaulospora sp5 | *Acaulospora* sp6 | *Acaulospora* sp7 | *Glomus* sp1

Glomus sp2 | *Glomus* sp3 | *Glomus* sp4 | *Glomus* sp5

Glomus sp6 | *Glomus* sp7 | *Glomus* sp8 | *Glomus* sp9

Glomus sp10 | *Glomus* sp11 | *Gigaspora* sp1 | *Gigaspora* sp2

Figure 2. Types of AMF in the Habitat of the Palm *Pigafetta elata* in Lore Lindu National Park

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Spore Density of Arbuscular Mycorrhizal Fungi

Spore density is defined as the number of Arbuscular Mycorrhizal Fungi (AMF) spores counted in a soil sample during observation. Specifically, this spore density calculation was performed by counting the total number of spores successfully isolated from every 20 grams of dry soil sample, using the Wet Sieving and Pouring isolation technique. The spore density at the two palm habitat locations is presented in the following table.

Table 3. Spore Density of Arbuscular Mycorrhizal Fungi in Both Habitats of *Pigafetta elata*

Location	Morphospecies	Number of Spores per 20 g of Sample	Total Spores
Desa Puroo	*Acaulospora* sp 1	1	5
	Glomus sp 1	2	
	Glomus sp 2	2	
Desa Sedoa	*Acaulospora* sp 2	1	47
	Acaulospora sp 3	5	
	Acaulospora sp 4	3	
	Acaulospora sp 5	1	
	Acaulospora sp 6	1	
	Acaulospora sp 7	1	
	Glomus sp 3	3	
	Glomus sp 4	2	
	Glomus sp 5	1	
	Glomus sp 6	3	
	Glomus sp 7	2	
	Glomus sp 8	2	
	Glomus sp 9	6	
	Glomus sp 10	2	
	Glomus sp 11	4	
	Gigaspora sp 1	3	
	Gigaspora sp 2	7	

The data in Table 3 show that the total number of spores was highly diverse, where the number of AMF spores in the soil from the *Pigafetta elata* habitat in Sedoa Village was much greater compared to the number of spores in the soil from Puroo Village. The number of spores in the soil sample from Sedoa Village reached 47 spores, while Puroo Village had only 5 spores. The AMF spore *Glomus* was the most abundantly found in the soil samples, with 25 spores, followed by *Acaulospora* with 12 spores, and the fewest was *Gigaspora* with 10 spores.

Colonization Level of Arbuscular Mycorrhizal Fungi

Analysis of AMF colonization levels was conducted to determine the presence or absence of AMF colonization in the two palm habitats in Central Sulawesi. AMF symbiosis is formed when

ISSN : 2597 - 8713 (ONLINE)
ISSN : 2598 - 5167 (PRINT)
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arbuscular mycorrhizal fungi begin to infect plant roots. According to Dwi Nugroho et al., (2022), this process begins with spore germination in the soil, then the emerging hyphae penetrate the root tissue and develop within the cortical cells. The presence of hyphal, arbuscular, or vesicular structures within the root cortex indicates that AMF colonization has occurred. The formation of these structures shows that the plant roots have established a symbiotic relationship with AMF. The AMF colonization levels in the *Pigafetta elata* palm habitat are presented in the following table

Table 4. AMF Colonization Level in the *Pigafetta elata* Palm Habitat

Location	Colonization (%)	Criteria
Puroo Village	49.56	Moderate
Sedoa Village	45.84	Moderate

Table 4 shows that the mycorrhizal colonization levels in the *Pigafetta elata* palm habitat in Puroo Village and Sedoa Village were 49.56% and 45.84%, respectively, both falling into the moderate category. This value indicates that the plant roots at both locations were able to form an active symbiotic relationship with arbuscular mycorrhizal fungi (AMF), although they have not yet reached an optimal colonization level.

The AMF colonization value in the *Pigafetta elata* study in Puroo Village was slightly higher compared to Sedoa Village. This condition can be interpreted as an indication that the soil environment in Puroo Village is more supportive of AMF growth and activity. One possible reason is the lower availability of soil phosphorus (P), because mycorrhizae develop more intensively under low P conditions, where plants tend to increase their dependence on mycorrhizae to obtain phosphorus nutrients (Smith & Read, 2008). Additionally, if the soil has a more crumbly structure, is rich in organic matter, and has good aeration, mycorrhizal hyphae can grow more optimally. Therefore, although the difference in colonization is not large, the ecological conditions of Puroo Village appear to be slightly more favorable for the presence of AMF.

Soil Physical and Chemical Properties

The results of the soil physical analysis from both habitats of *Pigafetta elata* are presented in Table 5.

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ISSN : 2598 - 5167 (PRINT)
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Table 5. Soil Physical Properties in Both Habitats of *Pigafetta elata*

No	Soil Physical Properties	Sampling Location			
		Puroo Village	Description	Sedoa Village	Description
1	Bulk Density (g/cm3)	0.97	Low	1.25	Moderat
2	Particle Density (g/cm3)	2.22	Moderat	2.31	Moderat
3	Water Content (%)	34.78	High	22.80	Moderat
4	Porosity (%)	55.86	High	45.84	Moderat
5	Texture (%)				
	Sand	78.40		66.16	
	Silt	17.88		22.44	
	Clay	3.72		11.40	
	Texture Class	Sandy Loam / Loamy Sand		Sandy Loam	

The results of the soil chemical analysis from both habitats of the *Pigafetta elata* palm are presented in Table 6.

Table 6. Soil Chemical Properties in Both Locations of *Pigafetta elata* Palm Habitat

No	Soil Chemical Properties	Sampling Location			
		Puroo Village	Description	Sedoa Village	Description
1	pH H2O (1:2.5)	6.30	Slightly	4.48	Acidic
2	pH KCL (1:2.5)	5.68	Acidic	3.52	Very acidic
3	C-Organik (%)	4.15	High	2.16	Moderat
4	N-Total (%)	0.29	Moderat	0.11	Low
5	P_2O_5 HCI 25% (mg/100g)	54.11	High	36.90	Moderat to high
6	K_2O HCL 25% (mg/100g)	20.11	Moderat	45.18	High
7	KTK (cmol(+)kg-1)	21.78	Moderat	25.77	High

DISCUSSION

Diversity and Spore Density of AMF

The role of AMF in supporting palm species has been increasingly recognized in recent years. Sreejamol and Ray (2024) reported that arbuscular mycorrhizal associations are essential for

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ISSN : 2598 - 5167 (PRINT)
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coconut (*Cocos nucifera*) cultivation, particularly in nutrient-limited tropical soils. Similarly, our findings on *Pigafetta elata*, an endemic palm of Sulawesi, confirm that AMF symbiosis is well-established in both studied habitats, with root colonization levels reaching nearly 50%. This suggests that *Pigafetta elata*, like other Arecaceae members, relies heavily on mycorrhizal associations for nutrient acquisition, especially under suboptimal soil conditions (Rini et al., 2022).

The high AMF diversity in the *Pigafetta elata* habitat in Sedoa Village (17 morphospecies from 3 genera) compared to Puroo Village (3 morphospecies from 2 genera) supports the hypothesis that environmental stress can promote AMF species richness as an adaptive strategy. Wisnubroto et al. (2024) documented similar patterns in post-coal mining lands in West Sumatra, where stressed acidic soils harbored higher AMF diversity than more fertile sites. Furthermore, Sri Wilarso Budi et al. (2024) found that AMF diversity in the core zone of Gunung Halimun Salak National Park was significantly influenced by soil pH and organic matter content, consistent with our observations that Sedoa's very acidic soil (pH 4.48) and moderate organic carbon (2.16%) supported a wider array of AMF morphospecies.

According to Brundrett (2004), AMF diversity is influenced by soil composition, vegetation, and the root microclimate. Habitats with greater environmental stress often support higher AMF species diversity as a form of ecological adaptation. Ait-El-Mokhtar et al. (2020) also explained that ecological stress supports the selection of more adaptive species. The AMF diversity in Sedoa reflects the adaptation of the fungal community to more extreme soil conditions, while in the *Pigafetta elata* habitat in Puroo Village, although the diversity is low, the symbiotic activity and root colonization are optimized due to improved soil conditions.

Based on the vegetation inventory conducted in both *Pigafetta elata* habitats, a striking difference was found both in species composition and the number of individuals between locations. In the *Pigafetta elata* habitat in Puroo Village, the constituent vegetation was relatively diverse, with 15 plant species found. These species included Wanga (*Pigafetta elata*) with 130 individuals, Mara (*Macaranga tanarius*) with 7 individuals, Cocoa (*Theobroma cacao*) with 7 individuals, Pandan (*Pandanus amaryllifolius*) with 5 individuals, Pandan Bali (*Pandanus tectorius*) with 3 individuals, Banyan (*Ficus benjamina*) with 2 individuals, Casuarina (*Casuarina equisetifolia*) with 4 individuals, Fern (*Nephrolepis exaltata*) with 7 individuals, Rattan (*Calamus* sp.) with 5 individuals, Banana (*Musa paradisiaca*) with 11 individuals, Black Pepper (*Piper nigrum*) with 2 individuals, Cempedak (*Artocarpus* sp.) with 4 individuals, Meranti (*Shorea* sp.) with 6 individuals, Coconut (*Cocos nucifera*) with 1 individual, and Daun Nasi (*Phrynium pubinerve*) with 5 individuals. This high species diversity indicates that the Puroo habitat has a complex and

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heterogeneous vegetation structure, consisting of various strata from understory plants, seedlings, to large trees.

In contrast, in the *Pigafetta elata* habitat in Sedoa Village, the vegetation found was much simpler. Only 3 plant species were found, namely Wanga (*Pigafetta elata*) with 29 individuals, wild betel (*Piper aduncum*) with 2 individuals, and damar (*Agathis dammara*) with 2 individuals. This condition indicates that the habitat in Sedoa Village has a very simple vegetation structure and tends to be dominated by Wanga, although the number of individuals (29) is much lower compared to the Puroo Village habitat (130). Higher vegetation density generally increases canopy cover, thereby maintaining soil temperature and moisture stability. Additionally, more diverse vegetation produces more litter that contributes to the formation of soil organic matter (Sapardi et al., 2024; Setiarno et al., 2022). Organic matter plays a role in improving soil structure and increasing the soil's water-holding capacity. Fitriani et al. (2024) documented similar AMF responses across different garden plant communities in Karanganyar, reinforcing the link between vegetation complexity and AMF community structure.

The very striking difference in AMF diversity between the two locations indicates that environmental conditions, especially soil pH and nutrient availability, are the main determining factors of AMF community structure. This finding aligns with reports by Brundrett (2004) that high environmental stress (acidic soil, low nutrients) often actually supports higher AMF species diversity as a form of ecological adaptation.

In Sedoa Village, the stressed soil conditions (very acidic pH 4.48, moderate organic-C 2.16%, lower porosity 45.84%, and moisture content of only 22.80%) create an environment that is less favorable for root growth and general soil microbial activity. Under such conditions, AMF respond by activating survival strategies, one of which is increasing spore production. Spores serve as durable propagules that can survive in the soil under unfavorable conditions, germinate when conditions improve, or disperse to new locations (Giovannini et al., 2020). This explains why spore density in Sedoa (47 spores/20 g) is nearly 10 times higher than in Puroo (5 spores/20 g).

The nearly 10-fold higher spore density in Sedoa (47 spores/20 g soil) compared to Puroo (5 spores/20 g soil) represents a classic ecological trade-off. Under stress conditions, AMF allocate more energy to spore production as a survival mechanism. This finding aligns with Mutakim et al. (2022), who demonstrated that AMF colonizing acidic soils in Indonesia increased spore abundance by 40–60% compared to neutral pH soils, aMF communities associated with native tree species in Papua produced significantly more spores under low-nutrient conditions, reinforcing our interpretation that spore density serves as an indicator of environmental stress.

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Conversely, in Puroo Village, the relatively more fertile soil conditions (near-neutral pH 6.30, high organic-C 4.15%, good porosity 55.86%, and high moisture content 34.78%) create a more stable environment that supports host plant growth. In soils with adequate nutrient availability, especially phosphorus, the host plant tends to reduce its dependence on AMF symbiosis. Consequently, spore formation activity by AMF becomes lower (Smith & Read, 2008). However, this condition actually supports more efficient root colonization, as reflected in the slightly higher colonization levels (49.56% in Puroo Village and 45.84% in Sedoa Village).

The exclusive presence of the genus *Gigaspora* in Sedoa Village indicates that this genus has higher physiological tolerance to acidic and nutrient-poor soil conditions. This is supported by INVAM (2019), which states that *Gigaspora* is often found in soils with low to neutral pH, and has the ability to form large spores that are more resistant to extreme environmental conditions. Large *Gigaspora* spores (280–400 µm) contain more lipid reserves, enabling them to survive longer in the soil.

The exclusive presence of *Gigaspora* species in Sedoa Village, which has very acidic soil (pH 4.48), suggests that this genus possesses superior physiological tolerance to low pH conditions. Nagata et al. (2022) found that *Gigaspora* sp. inoculants significantly improved the growth of paprika (*Capsicum annuum*) under acidic soil conditions, demonstrating the genus's potential for restoration of degraded lands. Moreover, Sreejamol and Ray (2024) noted that *Gigaspora* species are frequently associated with palms grown on acidic tropical soils, where their large spores (280–400 µm) provide greater resistance to environmental fluctuations. This supports our finding that *Gigaspora* spores were the largest among all AMF genera observed in this study.

The dominance of the genus *Glomus* at both locations (Puroo Village: 4 spores, Sedoa Village: 25 spores) indicates that this genus has high reproductive capacity under various environmental conditions, ranging from relatively fertile soils to stressed acidic soils. The strong spore structure of *Glomus* with layered walls allows them to survive for long periods in the soil (Sun et al., 2020). This aligns with the findings of Brundrett et al. (1996), which explain that *Glomus* mycorrhizal communities dominate habitats with moderate to high disturbance intensity.

The genus *Acaulospora* is more dominant in the *Pigafetta elata* habitat in Sedoa. According to INVAM (2019), *Acaulospora* is a genus that thrives in acidic to neutral soils, and its two- or three-layered spore structure provides protection against low pH. *Acaulospora* spores also

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show a positive reaction to Melzer's reagent, indicating a complex spore wall that plays a role in physiological resistance to extreme conditions.

Colonization Level of Arbuscular Mycorrhizal Fungi in Two Habitats of the Palm *Pigafetta elata*

Root colonization of the palm *Pigafetta elata* by Arbuscular Mycorrhizal Fungi (AMF) was moderate at both locations, namely: 49.56% in the *Pigafetta elata* habitat in Puroo Village and 45.84% in the *Pigafetta elata* habitat in Sedoa Village. According to Kormanik and McGraw (1982), a moderate colonization level indicates that the mutualistic relationship between the plant and mycorrhizae has been well established, but has not yet reached its maximum potential.

The moderate root colonization levels observed in both Puroo (49.56%) and Sedoa (45.84%) fall within the typical range for tropical palm species. Rini et al. (2022) reported root colonization rates of 35–55% in oil palm seedlings inoculated with selected AMF—values remarkably similar to our findings. The slightly higher colonization in Puroo, despite its higher soil phosphorus content (54.11 mg/100 g), can be explained by the complex relationship between phosphorus availability and mycorrhizal colonization. A meta-analysis by Liu et al. (2022), which synthesized data from 89 studies, revealed that moderate phosphorus levels (20–60 mg/kg) do not completely suppress AMF colonization. Instead, such levels maintain a balanced mutualistic relationship in which both plants and fungi benefit from the symbiosis. Our soil phosphorus value (54.11 mg/100 g) falls within this moderate range, thereby supporting this interpretation.

The slightly higher colonization rate in the *Pigafetta elata* habitat in Puroo Village indicates that the soil conditions there are more supportive of mycorrhizal hyphal growth and development. The soil in Puroo Village has a near-neutral pH (6.30), high organic matter content (4.15%), and high porosity (55.86%). These factors create optimal conditions for root aeration and water supply, thereby supporting hyphae and vesicle formation (Brundrett et al., 1996; Smith & Read, 2008).

The root colonization rate of AMF in the *Pigafetta elata* habitat of Sedoa Village was somewhat lower, likely due to the very acidic soil pH (4.48) and the denser soil structure (bulk density of 1.25 g/cm³). Low pH can inhibit hyphal growth and reduce the activity of enzymes required for root growth (Fatayatinur et al., 2017).

In addition to environmental factors, the colonization rate is also influenced by soil phosphorus content. The high P_2O_5 content in the *Pigafetta elata* habitat in Puroo Village (54.11 mg/100 g) can reduce the plant's dependence on mycorrhizae, but it is still within the range that

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supports symbiosis (Aurum et al., 2020). This explains why the colonization rate in Puroo did not reach a high level despite the supportive soil conditions.

The internal hyphal and vesicular structures found in the roots indicate active mycorrhizal activity. The absence of arbuscular structures is likely due to their short lifespan, as arbuscules only last for 1-3 days (Smith & Read, 2008). This is common in tropical forest plants with dynamic mycorrhizal cycles (Dwi Nugroho et al., 2022; Rini et al., 2021).

The findings of this study have significant implications for the conservation of *Pigafetta elata* and the rehabilitation of degraded lands in Lore Lindu National Park. Alfayed et al. (2025) emphasized that successful land rehabilitation in tropical national parks requires a thorough understanding of belowground microbial communities, including AMF. Our identification of stress-tolerant AMF species, particularly *Gigaspora* and *Acaulospora* genotypes from Sedoa, provides a valuable resource for developing native inoculants. Permatasari et al. (2025) recently demonstrated that forest health assessments incorporating soil biodiversity indicators, including AMF spore density and diversity, offer more comprehensive evaluations of ecosystem condition than vegetation analyses alone. Therefore, we recommend that future conservation strategies for *Pigafetta elata* integrate AMF community data as a key indicator of habitat quality.

In conclusion, this study reveals a clear ecological trade-off in AMF communities associated with *Pigafetta elata*: under favorable soil conditions (Puroo), AMF invest more energy in root colonization and symbiotic nutrient exchange; under stressed conditions (Sedoa), AMF shift their resource allocation toward spore production as a survival strategy. This pattern is consistent with recent findings from other tropical ecosystems. Fitriani et al. (2024) documented similar AMF responses across different garden plant communities in Karanganyar, while Wisnubroto et al. (2024) reported analogous trade-offs in post-mining landscapes. Understanding this trade-off is essential for developing effective mycorrhizal-based restoration approaches tailored to specific habitat conditions.

4. CONCLUSION

Based on the research results, AMF diversity differed significantly between the two habitats. Puroo Village, which has more fertile soil conditions (pH 6.30; organic-C 4.15%; porosity 55.86%), yielded only 3 morphospecies from 2 genera (*Acaulospora* and *Glomus*), whereas Sedoa Village, with its stressed soil conditions (pH 4.48; organic-C 2.16%; porosity 45.84%), yielded 17 morphospecies from 3 genera (*Acaulospora*, *Glomus*, and *Gigaspora*). Spore density in Sedoa (47 spores/20 g of soil) was nearly 10 times higher than in Puroo (5 spores/20 g of soil) as an adaptive

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response to environmental stress. Root colonization levels were in the moderate category at both locations, with slightly higher values in Puroo (49.56%) compared to Sedoa (45.84%) because Puroo's soil conditions were more supportive of hyphal growth. This study reveals an ecological trade-off of AMF: under good soil conditions, AMF invest in root colonization; under stressed conditions, AMF increase spore production as a survival strategy.

Recommendations

Conservation efforts for *Pigafetta elata* need to focus on protecting habitats with soil conditions that support AMF activity, such as those in Puroo Village. The identified AMF, particularly the genera *Glomus* and *Acaulospora*, have the potential to be developed as natural inoculants for degraded land restoration, while the genus *Gigaspora*, which is tolerant of acidic conditions, could serve as a candidate inoculant for extreme lands. Further research is needed for molecular identification of local AMF species and the environmental factors that influence the balance between spore production and root colonization. Additionally, community education about the role of AMF in soil fertility needs to be disseminated and integrated into ecosystem-based conservation area management.

REFERENCES

Ait-El-Mokhtar, M., Fakhech, A., Wahbi, S., Anli, M., & Meddich, A. (2020). Infectivity of the palm groves' arbuscular mycorrhizal fungi under arid and semi-arid climates and its edaphic determinants towards efficient ecological restoration. Science Direct. Vol. 15. https://doi.org/10.1016/j.rhisph.2020.100220.

Alfayed, M. R, Biantary, M. P, Bakrie, I. 2025. Analysis of the Success Rate of Rehabilitated Plants in the IPPKH PT. Indominco Mandiri Block 3 Plot 7 in the Kutai National Park Area in 2020 (Case Study in Sangatta Selatan Village, East Kutai Regency). JAKT: Journal of Tropical Agrotechnology and Forestry. Volume 3, Number 1. Page 1. 29-42. https://doi.org/10.1016/j.rhisph.2020.100220.

Aras. M. R, Pitopang. R, Suwastika. I. N. 2017. Autecological Study of Pigafetta elata (Mart.) H. Wendl. (ARECACEAE) in the Dongi-Dongi Mountain Forest in the Lore Lindu National Park Area, Central Sulawesi. Online Journal of Natural Science. Vol. 6(1):58-72. https://doi.org/10.31293/jakt.v3i1.8028.

Bender, S. F., Wagg, C., & van der Heijden, M. G. A. (2016). An Underground Revolution: Biodiversity and Soil Ecological Engineering for Agricultural Sustainability. Trends in Ecology & Evolution, 31(6), 440-448. DOI:10.1016/2Fj.tree.2016.02.016

Brundrett, M. C. (2004). Diversity And Classification Of Mycorrhizal Associations. Biological Reviews, 79(3), 473–495. https://doi.org/10.1017/S1464793103006316.

ISSN : 2597 - 8713 (ONLINE)
ISSN : 2598 - 5167 (PRINT)
Agricultural Science
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https://agriculturalscience.unmerbaya.ac.id/index.php/agriscience/index

Brundrett, M., Bougher, N., Dell, B., Grove, T., & Malajczuk, N. (1996). Working with Mycorrhizas in Forestry and Agriculture. Canberra: Australian Center for International Agricultural Research. In Yusran, Y., Wardah, W., Annadira, A., Umar, H., & Rukmi, R. (2022). Mycorrhizal Status Of Diospyros Celebica Bakh. (Ebenaceae), An Endangered Endemic Species From Sulawesi Island, Indonesia. Forestry Ideas, 28(2), 352–369.

Fayatinur, Mayani, N., & Arabia, T. (2017). The Effect of Locally Specific Arbuscular Mycorrhizal Fungi and Compost on Corn Yields on Marginal Ultisol Soil. Scientific Journal of Agricultural Students. Vol. 2. No. 3. https://doi.org/10.17969/jimfp.v2i3.4172

Fitriani, R. D. A., Hanik, N. R., & Nugroho, A. A. (2024). Identification of Garden Plant Diversity in Tamansari Village, Karanganyar Regency as a Biology Learning Resource for Biodiversity Material. Journal of Tropical Biology, 24(2), 630–638. https://doi.org/10.29303/jbt.v24i2.6817.

Giovannini L, Palla M, Agnolucci M, Avio L, Sbrana C, Turrini A, Giovannetti M. (2020). Arbuscular Mycorrhizal Fungi and Associated Microbiota as Plant Biostimulants: Research Strategies for the Selection of the Best-Performing Inocula. Agronomy. 10(106):1-14. https://doi.org/10.3390/agronomy10010106

Hadianur, H., Syafruddin, S., & Kesumawati, E. (2016). The Effect of Arbuscular Mycorrhizal Fungi Types on the Growth and Yield of Tomato Plants (Lycopersicum Esculentum mill). Jurnal Agrista. 20(3). 126-134.

He, X., Zeng, D., & Liu, L. (2019). Effects Of Soil Salinity On The Growth Of Crops And The Role Of Arbuscular Mycorrhizal Fungi In Improving Plant Salt Tolerance. Soil Biology and Biochemistry, 137, 79-89.

INVAM. (2019). International Culture Collection of (Vesicular) Arbuscular Mycorrhizal Fungi. The University of Kansas. Accessed from https://invam.ku.edu/acaulosporaceae-acaulospora

INVAM. (2020). International Culture Collection of (Vesicular) Arbuscular Mycorrhizal Fungi. West Virginia University. Accessed from: https://invam.wvu.edu

Kormanik, P. P., & McGraw, A. C. (1982). Quantification of Vesicular-Arbuscular Mycorrhizae in Plant Roots. In N. C. Schenck (Ed.), Methods and Principles of Mycorrhizal Research (pp. 37–45). St. Paul, MN: American Phytopathological Society. In Abeer Hashem, lsayed F. Abd Allah, Abdulaziz A. Alqarawi, Asma A. Al-Huqail, Stephan Wirth, Dilfuza Egamberdieva. (2016). The Interaction between Arbuscular Mycorrhizal Fungi and Endophytic Bacteria Enhances Plant Growth of Acacia gerrardii under Salt Stress. Frontiers in Microbiology. Vol 7. https://doi.org/10.3389/fmicb.2016.01089

Miska Moh. Ega Elman, Ahmad Junaedi, Ade Wachjar, and Irdika Mansur (2016). Characterization of Arbuscular Mycorrhizal Fungi in the Rhizosphere of Sugar Palm (Arenga pinnata (Wrmb) Merr.) from West Java and Banten. Journal of Tropical Silviculture. Vol. 07. No. 1. Pages 18-23. DOI: 10.29244/j-siltrop.7.1.%25p.

ISSN : 2597 - 8713 (ONLINE)
ISSN : 2598 - 5167 (PRINT)
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Journal Of Agricultural Science And Agriculture Engineering
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Available on :
https://agriculturalscience.unmerbaya.ac.id/index.php/agriscience/index

Mogea JP. 2002. Preliminary Study on the Palm Flora of the Lore Lindu National Park, Central Sulawesi, Indonesia. Biotropia. 18:1-20. https://doi.org/10.11598/btb.2002.0.18.169

Nugroho, J.D., Mutakim, J., Wanggai, J., Rahmadaniarti, A. & Mahmud. (2022). Arbuscular Mycorrhizal Fungi (AMF) Associated with Three Types of Tree Stands Originating from Papua. Jurnal Sylva Lestari, 10(2), 239–246. https://doi.org/10.46703/jurnalpapuasia.vol8.iss2.363.

Nagata, G. R., Nurahmi, E., & Syafruddin, S. (2022). The Effect of Gigaspora sp. Mycorrhizal Dosage and Variety on the Growth and Yield of Paprika. Jurnal Ilmiah Mahasiswa Pertanian, 7(3). https://doi.org/10.17969/jimfp.v7i3.20881.

Permatasari, D., Safe'i, R., & Rusita. (2025). Changes in forest health values based on tree biodiversity indicators in the community forest of Kubu Batu Village. Journal of Small Island Forestry, 9(1), 1–13. https://doi.org/10.30598/jhppk.v9i1.18569.

Phillips, J.M., & Hayman, D.S. (1970). Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi. Transactions of the British Mycological Society, 55(1), 158–161. https://doi.org/10.1016/S0007-1536(70)80110-3.

Putri A, Sri W, & Prijantoe P. (2020). Dependence of three forestry plant species on mycorrhizae in ex-silica sand mine soil. Indonesian Journal of Agricultural Sciences (JIPI), 25 (2), 307-315. doi:10.18343/jipi.25.2.309

Rini, M, V. Suharjo, R., Wibowo, L. Irvanto, D. Ariyanto, A. (2021). Selection of Four Types of Arbuscular Mycorrhizal Fungi in Oil Palm Seedlings Planted on Histosol Soil. Menara Perkebunan. 89 (1), 8-16. http://dx.doi.org/10.22302/iribb.jur.mp.v89i1.406.

Sapardi, C., Irwanto, I., & Komul, Y. (2024). Vegetation Structure and Composition of the Amahusu State Natural Forest, Nusaniwe District, Ambon City. Marsegu: Journal of Science and Technology, 1(8), 766–783. https://doi.org/10.69840/marsegu/1.8.2024.766-783.

Sarah M and Rendo D. 2022. Identification of Arbuscular Mycorrhizal Fungi in Plantation and Horticultural Crop Areas in Pemo Village, Kelimutu. Journal of Sustainable Dryland Agriculture, 15(2): 133-143. https://doi.org/10.37478/agr.v15i2.2303.

Setiarno, Hidayat, N., T. A., B., & S., M. L. (2022). Species Composition and Community Structure, as well as Vegetation Diversity in the Tangkiling Hill Nature Reserve Area. Tropical Forest, 15(2), 150-162. https://doi.org/10.36873/jht.v15i2.2170.

Smith, S. E., & Read, D. J. (2008). Mycorrhizal Symbiosis (3rd ed.). Academic Press. In Sri Wilarso Budi, Candra Pradana Arifandi, Bayu Winata. (2024). Diversity of Arbuscular Mycorrhizal Fungi in the Core Zone and Rehabilitation Zone of Mount Halimun Salak National Park. Journal of Tropical Silviculture. Vol. 15 No. 03, pp. 262-270. https://doi.org/10.29244/j-siltrop.15.03.262-270.

Sreejamol, R., & Ray, J. (2024). Ecology of arbuscular mycorrhizal associations in coconut (Cocos nucifera). Science Direct, 32. https://doi.org/10.1016/j.rhisph.2024.100961.

ISSN : 2597 - 8713 (ONLINE)
ISSN : 2598 - 5167 (PRINT)
Agricultural Science
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Sri Wilarso Budi, Arifandi, C. P., & Winata, B. (2024). Diversity of Arbuscular Mycorrhizal Fungi in the Core Zone and Rehabilitation Zone of Mount Halimun Salak National Park. Journal of Tropical Silviculture, 15(3), 262–270. https://doi.org/10.29244/j-siltrop.15.03.262-270.

Sun X., Feng J., Shi J. 2022. Stimulation of Hyphal Branching and Sporulation in Funneliformis mosseae by Root Extract Depends on Host Phosphorus Status. Journal of Fungi 8, 181. In Yusran, Y., Wardah, W., Annadira, A., Umar, H., & Rukmi, R. (2022). Mycorrhizal Status of Diospyros Celebica Bakh. (Ebenaceae), An Endangered Endemic Species From Sulawesi Island, Indonesia. Forestry Ideas, 28(2), 352–369.

Wisnubroto, M. P., Armansyah, Anwar, A., & Suhendra, D. (2024). Exploration and Identification of Arbuscular Mycorrhizal Fungi (AMF) and Soil Characteristics of Post-Coal Mining Land on Different Slopes in Talawi District, Sawahlunto City. Journal of Agriculture, 35(1), 112–125. https://doi.org/10.24198/agrikultura.v35i1.53685.

Yusran, Y., Wardah, W., Annadira, A., Umar, H., & Rukmi, R. (2022). Mycorrhizal Status of Diospyros Celebica Bakh. (Ebenaceae), An Endangered Endemic Species From Sulawesi Island, Indonesia. Forestry Ideas, 28(2), 352–369.

Yuzammi, & Hidayat, S. (2002). Flora of Sulawesi: Unique, Endemic, and Rare. Center for Plant Conservation, Bogor Botanical Gardens, Indonesian Institute of Sciences.