



Mycorrhizal Status of Several Plants and Soil Characteristics around the Poboya Gold Mining Area, Palu City, Central Sulawesi, Indonesia

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Abstract

*in Central Sulawesi Province, there are 26 conservation areas in the form of National Parks, Nature Reserves, Grand Forest Parks, Wildlife Sanctuaries, Nature Parks, Marine Parks and Hunting Parks spread throughout the Regency. However, at present, the conservation area is threatened by both legal and illegal mining activities, such as gold and nickel mining, which of course threatens the sustainability of these biological resources and land. The research was conducted around gold mining area, Poboya village, Palu Municipality, Central Sulawesi, Indonesia. The mining area is part of the Poboya Forest Park (Tahura), which is one of the important conservation areas in Central Sulawesi, Indonesia. This study aims to determine mycorrhizal status of several plant species and soil characteristics around the gold mining area of Poboya. The results showed that there were 33 types of local plants found in the gold mining area of Poboya Village, Palu, Central Sulawesi. Types of *Acacia nilotica* and *Senna siamea* are the most dominant plant species compared to other plant species. The highest percentage of Arbuscular mycorrhizal fungi colonization was found in *Tectona grandis* L., which was 67.6% and the lowest was in *Opuntia* sp, which was 2.3% and several plant species were not colonized on the roots such as *Imperata cylindrical*, *Cyperus rotundus*, *Piper aduncum* and *Corypha* sp. This study will allow us to know the mycorrhizal status of plants in the Poboya gold mining area, Central Sulawesi, in order to be used in the post-mining land reclamation process in the future.*

Key words: Conservation, Gold Mining Area, Arbuscular mycorrhizal fungi, Soils

Introduction

Wawo et al (2017) stated that the gold mining area managed by the people in Poboya Village is $\pm$ 45 to 50 ha. This mining process uses the amalgamation method, namely the process of bonding gold using mercury (Hg) and cyanide, which have the potential to pollute the surrounding environment. Gold mining activities besides having a positive impact can also have a negative effect on the environment and agricultural land, such as decreasing soil quality, loss of nutrients, decreasing groundwater levels and loss of vegetated areas in the area. It is hoped that the vegetation of the ex-gold mining land can be reused for agricultural land and can form a new better ecosystem. One way to accelerate planting in ex-mining land is by utilizing arbuscular mycorrhizal fungi (AMF) which can form symbiosis with host plants that are tolerant of degraded lands due to ex-mining.

AMF is a form of symbiosis between roots of the plant and fungi. It is reported that about 90% of plant species have a symbiosis with mycorrhizal (Lanfranco et al., 2016). They can form mutualistic symbiosis

association with flowering plants, mosses, and ferns (Begum et al., 2019). AMF associates with plant species by colonizing plant roots and developing mycelium networks in the rhizosphere to facilitate nutrient uptake and to provide other benefits to their host plants. These benefits can be physiological, nutritional and ecological (Rodrigues & Rodrigues., 2014). FMA can increase land productivity and crop yields through mechanisms increasing availability uptake of P, Fe and Zn nutrients (Amani et al., 2021; Battini et al., 2017; Grümberg et al., 2014), increase resistance against drought, pests, and disease, plays an important role in cycle nutrients, and improve ecosystem stability (Marizal et al., 2016). Therefore, exploring and managing AMF has important and sustainable consequences for agricultural and natural ecosystems.

Research on the diversity of vegetation and its mycorrhizal status in mining areas has been carried out in Indonesia (Purnomo et al., 2015; Prasetyo et al., 2019; Isnaniarti et al., 2018; Riswan et al., 2015). However, similar research has never been conducted in mining areas in Central Sulawesi province, either in gold or nickel mining areas.

This research is one solution to overcome these problems, where gradually exploration activities will be carried out on colonization of AMF on the roots of several plant species and soil characteristics in mining areas in Central Sulawesi, permanent storage and propagation of these mycorrhizal fungi isolates, developing cultivation techniques by finding the best method and growing medium, and its application as a post-mining Phyto-Bioremediation technology in Central Sulawesi, so as to reduce the impact of land pollution by heavy metals from the mining process. The strategic issue that underlies the research is the need for information on the diversity of local plant species that are endemic to Sulawesi and their symbiosis with AMF which are still under-explored, especially in mining areas in Central Sulawesi Province. Many of these local plant species and mycorrhizal fungi have ethnobotanical values with local indigenous peoples as well as their potential in the future as a package of Phyto-Bioremediation Technology on ex-gold and nickel mining areas that have been polluted by heavy metals. This study aims to determine colonization of AMF in the roots of several plant species and the physical and chemical properties of the soil around the gold mining area, Poboya village, Palu Municipality, Central Sulawesi, Indonesia.

Material and Methods

Studi Sites

Sampling of plants, roots and soil was carried out at several locations around the gold mining area in Poboya Village, Palu, Central Sulawesi (Figure 1), as follows: Poboya 1 (271m asl, coordinate S 01°52.847' E 119°54.847), Poboya 2 (288m asl, coordinate S 00°52.680' E 119°55.089), Poboya 3 (436m asl, coordinate S 01°51.850' E 119°55.778), Poboya 4 (412m asl, coordinate S 00°51.990' E 119°55.558), Poboya 5 (199m asl, coordinate S 00°52.502' E 119°55.665).

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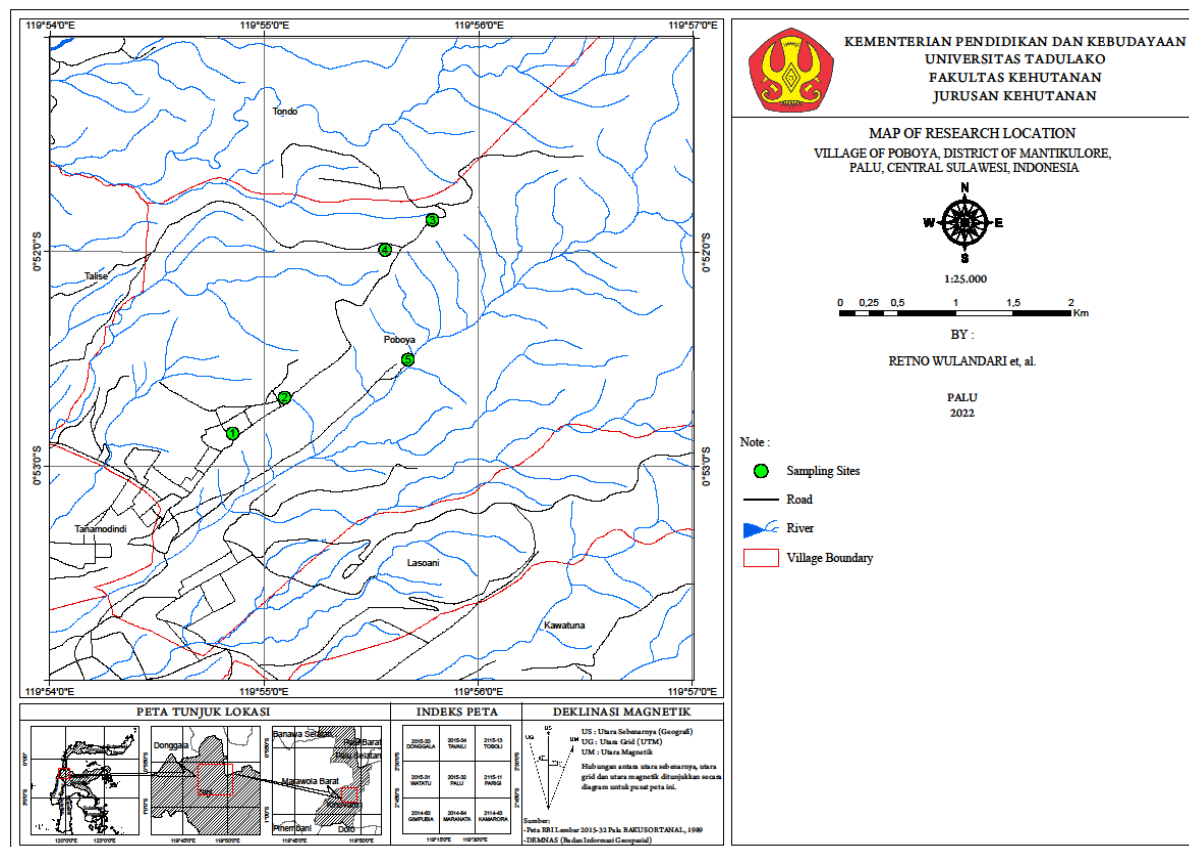


Figure 1. Map of Research location in Poboya gold mining area, Palu, Central Sulawesi, Indonesia.

Methods of Observing plant species

The method used in this research is a survey method through vegetation analysis by means of double plots with a size of 20 m x 20 m in which there are observation plots according to growth level. Observation plots of 2 m x 2 m for observation of seedlings and understorey plants, 5 m x 5 m for observation of saplings, 10 m x 10 m for observation of poles, 20 m x 20 m for observation of trees. Identification of plant species can use the help of a plant determination key or local tree identifiers. Unknown species are founded in the field, a sample herbarium of the plant is made to be identified by the Sulawesi Biological Resources Unit, Tadulako University. Identifying local tree species for land revegetation by using a Questionnaire (Field Data Sheet).

Arbuscular mycorrhizal fungi colonization.

Observation of AMF colonization on plant roots was carried out based on the Phillip and Hayman (1970) protocol. The roots that had been collected from the field were washed and cut into 1 cm pieces, then stored in 10% KOH solution for 24 hours at room temperature or at 90°C for 1 hour. These roots were then washed again in running water to clean and remove KOH. Then these roots were stored in 4% NaOCL solution for 10 minutes for bleaching. After that, the roots were washed again with tap water, then added 1% HCL in the tube and allowed to stand for 4 minutes, then the solution was discarded. Then these roots were stained with a trypan blue solution (0.05%) which had been prepared in a solution (lactic acid, glycerol and water with ration 2:2:1), then stored for 24 hours at room temperature or at 90°C for 1 hour. Excess stain is cleaned with a staining solution of lactic acid, glycerol and water (2:2:1). Furthermore, these root segments were placed on a microscope slide and observed AMF colonization under a microscope. The presence of AMF in roots is indicated by the presence of AMF structures in the roots such as hyphae, vesicles or arbuscules).

Persentase FMA colonization was calculated based on formula as proposed by Brundrett et al., (1996)

$$\frac{\text{Infected roots}}{\text{Total of observed roots}} \times 100\%$$

Level of AMF colonization was classified based on O'Connor et al. (2001), namely: Not colonized (0% colonization value), Low (<10% colonization value), Medium (10-30% colonization value), and High (>30% colonization value).

AMF exploration was carried out by taking soil and root samples of all types of plants. Observations on soil samples for spore isolation were carried out by the wet filter pour method and followed by the centrifugation method. Spores with complete morphological structure were isolated. Some of the isolated spores were then prepared for identification (Brundrett et al., 1996).

Observation of soil chemical properties was carried out by taking soil samples at a depth of 0-20 cm from the soil surface using a soil drill. In the four ex-mining areas, composite soil samples were taken for each so that 4 soil samples were obtained. Furthermore, the samples were analyzed in the soil laboratory to determine the physical and chemical properties of the soil. Soil chemical properties were determined based on standard protocols, namely; Organic C (Walkley-Black method, Walkley and Black 1934) Total N (Kjeldahl method (Kjeldahl 1883), P availability (Bray and Kurtz (1945), Soil pH (digital pH meter) and soil textures (pipette method).

Data Analysis

Data of percentage of arbuscular mycorrhizal fungi colonization was analyzed by using analysis of variance (ANOVA) SPSS Software (IBM SPSS Statistics 25, Armonk, NY, USA) and further test by honest significant difference (5%) to determine the significance between plant species.

Results and Discussion

The results showed that there were 33 plant species found at the research site, which were divided into 6 plant species in the grasslands and 33 plant species in vegetated land in the Poboya gold mining area. These plant species had varying percentages of colonization by arbuscular mycorrhizal fungi (AMF), which are presented in table 1.

The results show that as many as 29 plant species colonized AMF, and 4 species did not colonize AMF. The type of AMF found in the soil collected from this study site was *Glomus sp*, while the fungal structures found in the roots of plants infected by AMF were hyphae and vesicles in the roots (Figure 2). The presence of both fungal structures in the root cells indicates the presence of AMF colonization, as stated in the statement Miller et al., (1999), Stenlund & Charvar (1994) dan Wu et al., (2009) that mycorrhizal plants are characterized by the presence of hiphae and vesicles in their roots. The results of a study by Tawaraya et al., (2003) also showed that of the 22 plant species in peat swamp forest, 17 species showed colonization of arbuscular mycorrhizal fungi. In addition, they also reported that the AMF colonization varied from one plant to another, there were high, medium and low categories.

Thirteen plant species had a high percentage of AMF colonization, namely; *Tamarindus indica*, *Leucaena leucocephala*, *Caloptropis gigantean*, *Tabernaemontana pandacacui*, *Samanea saman*, *Senna siamea*, *Gliricida sepium*, *Lannea coromandelica*, *Jatropha gossypifolia*, *Annona squamosal*, *Tectona grandis*, *Muntingia calabura*, *Lantana camara*. Ten plant species had a moderate percentage of AMF colonization, namely ; *Acacia nilotica*, *Acacia auricauliformis*, *Syzygium cummi*, *Mangifera minor*, *Cleome chelidonii*, *Terminalia catappa*, *Sida rhombifolia*, *Hibiscus tiliaceus*, *Themedo arguens* dan *Streblus asper*, while six types of plants have a low percentage of colonization, namely; *Ricinus communis*, *Opuntia sp*, *Cordyline australis*, *Santalum album*, *Andropogun sp*. dan *Abrus precatorius*. The remaining four types of plants, namely;

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Imperata cylindrical, *Cyperus rotundus*, *Piper aduncum* dan *Corypha* sp. The same results were also reported by Turjaman et al., (2018) who reported that several plant species in the peat swamp forest, North Sumatra were also not found colonization by AMF on their roots. They further explained that the low percentage of AMF colonization in several plant species in this study might be caused by several factors such as the interaction between AMF and the host, growth conditions, light conditions, temperature and competition for nutrients among microbes in the soil.

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Table 1. Colonization of Arbuscular Mycorrhizal Fungi (AMF) in the Roots of Plants Found at the research site

No .	Vernacular Name	Scientific Name	Family	Research location		Colonization (%)	Patterns of AMF Colonization		Category
				A	B		H	V	
1	Poi	<i>Tamarindus indica</i> L	Fabaceae	-	√	42.7±2.45 e	√	√	high
2	Tamalanja	<i>Leucaena leucocephala</i> (Lam.) de Wit.	Fabaceae	-	√	33.3±2.98 f	√	√	high
3	Akasia	<i>Acacia nilotica</i> (L.) Willd. ex. Del.	Fabaceae	-	√	13.9±0.34 kl	√	√	moderate
4.		<i>Acacia auriculiformis</i>	Fabaceae	-	√	25.0±0.93 h	√	√	moderate
5	Roviega	<i>Caloptropis gigantea</i> (L.) W.T. Aiton.	Apocynaceae	-	√	50.8±0.94 d	√	√	high
6	Kaulana	<i>Tabernaemontana pandacaqui</i> Lam.	Apocynaceae	-	√	41.8±1.00 e	√	√	high
7	Kauco	<i>Samanea saman</i> (Jacq.) Merr.	Fabaceae	-	√	61.2±1.10 b	√	√	high
8	Johar	<i>Senna siamea</i> Lamk.	Fabaceae	-	√	43.6±0.31 e	√	√	high
9	Gamal	<i>Gliricida sepium</i> (Jacq.) Steud.	Fabaceae	-	√	55.2±1.00 c	√	√	high
10	Kayu Jawa	<i>Lannea coromandelica</i> (Houtt.) Merr.	Anacardiaceae	-	√	35.7±1.50 f	√	√	high
11	Alicope	<i>Syzygium cummi</i> (L) Skeels	Myrtaceae	-	√	17.3±1.03 ij	√	√	moderate
12	Kulalo Lei	<i>Jatropha gossypifolia</i> L.	Euophorbiaceae	-	√	26.2±0.75 gh	√	√	high
13	Kulalo	<i>Ricinus communis</i> L.	Euophorbiaceae	-	√	3.7±0.60 p	√	√	low
14	Srikaya	<i>Annona squamosa</i> L.	Annonaceae	-	√	42.7±2.09 e	√	√	high
15	Jati	<i>Tectona grandis</i> L.	Verbenaceae	-	√	67.3±1.43 a	√	√	high
16	Taipa	<i>Mangifera minor</i> Lour.	Anacardiaceae	-	√	29.3±2.00 g	√	√	moderate
17	Bavavoa	<i>Cleome chelidonii</i> L.f	Capparaceae	-	√	15.7±1.00 jk	√	√	moderate
18	Lari	<i>Opuntia</i> sp.	Cactaceae	√	√	2,3±0.28 pq	√	√	low
19	Jono	<i>Imperata cylindrical</i> L.	Poaceae	√	√	0±0 q	-	-	Not colonized
20	Cendana	<i>Santalum album</i> L.	Santalaceae	-	√	9.7±0.20 mn	√	√	low
21	Panda	<i>Cordyline australis</i> (G. Forst.) Endl.	Asparagaceae	-	√	5.3±0 op	√	√	low
22	Talise	<i>Terminalia catappa</i> L.	Combretaceae	-	√	17.6±1.80 ij	√	√	moderate
23	Sibalaya	<i>Sida rhombifolia</i> L.	Malvaceae	-	√	12.3±1.01 lm	√	√	moderate
24	Kalibau	<i>Hibiscus tiliaceus</i> L.	Malvaceae	-	√	25.6±0.50 h	√	√	moderate
25	Kavoko	<i>Themeda arguens</i>	Poaceae	√	√	12.3±2.0 lm	√	√	moderate
26	Rumpu	<i>Andropogon</i> sp	Poaceae	-	√	3.3±0.10 pq	√	√	low

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27	Munta	<i>Cyperus rotundus</i> L.	Cyperaceae	√	√	0±0 q	-	-	Not colonized
28	Sirih hutan	<i>Piper aduncum</i> L.	Piperaceae	-	√	0±0 q	-	-	Not colonized
29	Katimunda	<i>Abrus precatorius</i> L.	Fabaceae	-	√	8.6±0.50 no	√	√	low
30	Lui	<i>Corypha</i> sp.	Arecaceae	-	√	0±0 q	-	-	Not colonized
31	Sule	<i>Streblus asper</i> Lour.	Moraceae	√	√	11.5±0.40 lmn	√	√	moderate
32	Kersen	<i>Muntingia calabura</i> L.	Muntingiaceae	-	√	42.6±2.50 e	√	√	high
33	Sidondo	<i>Lantana camara</i> L.	Verbenaceae	√	√	33.3±1.50 f	√	√	high

Keterangan ; A= Grass land, B= Vegetation land, H=Hyphae, V=Vesicle, Different letters mean significantly different at the 5% HSD test level

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Variation in AMF colonization as shown in the results of this study is due to many factors, for example differences in host plants in terms of their dependence on mycorrhizae (Kowalska et al., 2015), the ability of each type of AMF as well as edapite and climate factors (Gong et al., 2013). Varying levels of AMF colonization of plant roots in natural forests have also been reported (Becerra et al., 2007; Birhane et al., 2017; Melo et al., 2019; Retama-Ortiz., 2017; Songachan et al., 2011; Yang et al., 2011; Yusran et al., 2022). AMF infection in plant roots can be seen in figure 2 :

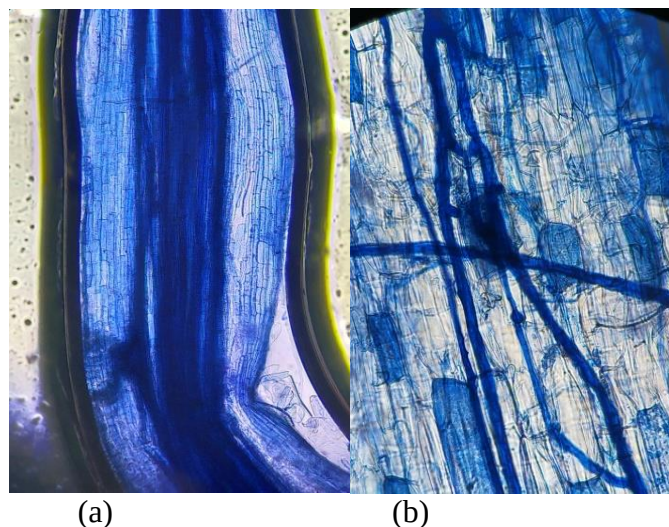


Figure 2. Roots not colonized by AMF (a), Roots colonized by AMF (b).

Soil characteristics at the study sites showed differences in several parameters (Table 2), so that it was thought to have an effect on the colonization level of the arbuscular mycorrhizal fungi. According to Islam et al., (2022) that soil quality greatly affects mycorrhizal infection in plant roots.

Table 2. Physical and chemical properties of the soil at the research sites

No.	Parameters	Soil sampling location	
		Grass land	Vegetation land
1.	pH (H ₂ O)	6.29	7.03
2.	C-organic (%)	2.23	2.16
3.	N-Total (%)	0.11	0.18
4.	Cation Exchange Capacity cmol (+)kg ⁻¹	18.97	21.88
5.	P ₂ O ₅ (ppm)	5.89	11.83
6.	Permeability (cm/jam)	9.76	17.13
7.	Bulk Density (gr/cm ³)	1.70	1.65
8.	Porosity (%)	32.26	37.78
9.	Soil texture	Sandy clay	Sandy clay

Conclusions

The results showed that there were 33 plant species found in the gold mining area of Poboya Village, Palu City, Central Sulawesi, Indonesia. These plant species had varying percentages of colonization by arbuscular mycorrhizal fungi (AMF). The highest percentage of AMF colonization was found in *Tectona grandis* L., namely 67.6% and the lowest was in *Opuntia* sp, namely 2.3% and several plant species were not colonized on the roots such as *Imperata cylindrical*, *Cyperus rotundus*, *Piper aduncum* and *Corypha* sp. This study will allow us to know the colonization of AMF in the root of plants in the Poboya gold mining area, Central Sulawesi, in order to be used in the post-mining land reclamation process in the future.

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References

- i. Amani Machiani M., Javanmard A., Morshedloo, M.R., Aghaee A., Maggi F., 2021. Funneliformis Mosseae Inoculation under Water Deficit Stress Improves the Yield and Phytochemical Characteristics of Thyme in Intercropping with Soybean. *Sci. Rep.* 11: 15279.
- ii. Battini F., Grønlund M., Agnolucci, M., Giovannetti M., Jakobsen I., 2017. Facilitation of Phosphorus Uptake in Maize Plants by Mycorrhizosphere Bacteria Article. *Sci. Rep.* 7: 4686.
- iii. Becerra A., Cabellob M., Chiarini f., 2007. Arbuscular mycorrhizal colonization of vascular plants from the Yungas forests, Argentina. *Ann. For. Sci.* 64: 765–772. DOI: 10.1051/forest:2007056
- iv. Begum N., Qin C., Ahanger M.A., Raza S., Khan M.I., Ashraf M., Ahmed N., Zhang L., 2019. Role of Arbuscular mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. *Front. Plant Sci.* 10: 01068
- v. Birhane E., Gebremedihin K.M., Tadesse T., Hailemariam M., Solomon N., 2017. Exclosures restored the density and root colonization of arbuscular mycorrhizal fungi in Tigray, Northern Ethiopia. *Ecological Processes.* 6:33. DOI 10.1186/s13717-017-0101-9
- vi. Bray R.H., Kurtz L.T. 1945. Determination of Total Organic and Available Forms of Phosphorus in Soils. *Soil Science* 59(1): 39–45. <http://dx.doi.org/10.1097/00010694-194501000-00006>
- vii. Brundrett, M., N.L. Bougher, B. Dell, T.S. Groove, N. Malajczuk. 1996. Working with Mycorrhizas in Forestry and Agriculture. Australian Centre for International Agricultural Research, Canberra, AU.
- viii. Gong, M.G.; Ming, T.; Zhang, Q.M.; Feng, X.X., 2012. Effects of climatic and edaphic factors on arbuscular mycorrhizal fungi in the rhizosphere of *Hippophae rhamnoides* in the Loess Plateau, China. *Acta Ecol. Sin.* 32: 62–67.
- ix. Grümberg B.C., Urcelay C., Shroeder M.A., Vargas-Gil S., Luna C.M., 2014. The Role of Inoculum Identity in Drought Stress Mitigation by Arbuscular mycorrhizal Fungi in Soybean. *Biol. Fertil. Soils.* 51: 1–10.
- x. Islam M., Al-Hashimi A., Ayshasiddeka M., Ali H., El Enshasy H.A., Dailin D.J., Sayyed R.Z., Yeasmin T., 2022. Prevalence of mycorrhizae in host plants and rhizosphere soil: A biodiversity aspect. *Plos One.* 17(3):e0266403.
- xi. Isnaniarti U.N., Ekyastuti W., Ekamawanti H.A., (2018). Suksesi Vegetasi Pada Lahan Bekas Penambangan Emas Rakyat di kecamatan Monterado Kabupaten Bengkayang. *Jurnal Hutan Lestari.* 6(1):198-207.
- xii. Kjeldahl J. 1883. A New Method for the Determination of Nitrogen in Organic Matter. *Zeitschrift für Analytische Chemie* 22: 366–382. <http://dx.doi.org/10.1007/BF01338151>
- xiii. Kowalska, I.K.; Konieczny, A.K.; Gastol, M.K.; Sady, W.K.; Hanusfajerska, E.K. Effect of mycorrhiza and phosphorus content in nutrient solution on the yield and nutritional status of tomato plants grown on rockwool or coconut coir. *Agric. Food. Sci.* 2015, 24, 39–51. [CrossRef]
- xiv. Lanfranco L., Bonfante P., Genre A., 2016. The mutualistic interactions between plants and arbuscular mycorrhizal fungi. *Microbiol Spectr.* 4.
- xv. Marizal S, Muzakir, Syariyah A., 2016. The Diversity of Arbuscular Mycorrhiza Fungus (AMF) Indigenous in Peanuts (*Arachis Hypogaea* L) Rhizosphere under Different Elevation. *J Trop Soils.* 21(2): 109-114

- xvi. Melo C.D., Walker C., Krüger C., Borges P.A.V., Luna S., Mendonça D., Fonseca H.M.A.C., Machado A.C., 2019. Environmental factors driving arbuscular mycorrhizal fungal communities associated with endemic woody plant *Picconia azorica* on native forest of Azores. *Annals of Microbiology*. 69:1309–1327. <https://doi.org/10.1007/s13213-019-01535-x>
- xvii. Miller R.M., Smith C.R., Jastrow J.D., Bever J.D., 1999. Mycorrhizal status of the genus *Carex* (Cyperaceae). *Am. J. Bot.* 86: 547– 553.
- xviii. O'Connor PJ, Smith SE, Smith FA. 2001. Arbuscular mycorrhizal association in the Southern Simpson desert. *Australian Journal of Botany*. 49:493-499.
- xix. Prasetyo R., Sasli I., Ramadhan T.H., 2019. Identifikasi Vegetasi dan Fungi Mikoriza Arbuskula (FMA) pada Lahan Bekas Tambang Identification of Vegetation and Arbuscular Mycorrhizal Fungi (AMF) in Former Mining Sites. *J. Agron. Indonesia*. 47(2):217-223
- xx. Purnomo D.W., Mgandhi M., Helmanto H., Witono J.R., 2015. Jenis-jenis tumbuhan reklamasi potensial untuk fitoremediasi di kawasan bekas tambang emas. *Pros. Sem. Nas. Masy. Biodiv. Indon.* 1(3): 496-500.
- xxi. Retama-Ortiz Y., Àvila-Bello C.H., Alarcón A., Ferrera-Cerrato R., 2017. Effectiveness of native arbuscular mycorrhiza on the growth of four tree forest species from the Santa Marta Mountain, Veracruz (Mexico). *Forest Systems*. 15(1): 1-9.
- xxii. Rodrigues K.M & Rodrigues B.F., 2014. Arbuscular Mycorrhizal (AM) Fungi and Plant Health. *Fungi in Biotechnology*, Ed. by: M. Gosavi. SIES College, Sion, Mumbai: 8-24.
- xxiii. Songachan L.S., Lyngdoh I., Highland K., 2011. Colonization of arbuscular mycorrhizal fungi in moderately degraded sub-tropical forest stands of Meghalaya, Northeast India. *Journal of Agricultural Technology*. 7(6): 1673-1684
- xxiv. Stenlund D.L., Charvat I.D., 1994. Vesicular arbuscular mycorrhizae in floating wetland mat communities dominated by *Typha*. *Mycorrhiza*. 4:131–137.
- xxv. Tawaraya K., Takaya Y., Turjaman M., Tuah S.J., Limin S.H., Tamai Y., Cha J.Y., Wagatsuma T., Osaki M., 2003. Arbuscular mycorrhizal colonization of tree species grown in peat swamp forests of Central Kalimantan, Indonesia. *Forest Ecology and Management*. 182(1-3): 381-386. [https://doi.org/10.1016/S0378-1127\(03\)00086-0](https://doi.org/10.1016/S0378-1127(03)00086-0)
- xxvi. Turjaman M., Herdyantara B., Fauliuna S.A., Agustini L., Irianto R.S.B., Hidayat A., Wahno I., Murdani., Tjahyono B., Indrayati H., 2018. Mycorrhizal colonization of indigenous tropical tree species grown in peat swamp forests of Sumatera, Indonesia. *IOP Conf. Series: Earth and Environmental Sciences*. 308 (2019) 012049
- xxvii. Walkley A.J., Black I.A. 1934. Estimation of soil organic carbon by the chromic acid titration method. *Soil Science* 37: 29–3
- xxviii. Wawo R.H.A., Widodo S., Jafar N., Yusuf F.N., 2017. Analisis Pengaruh Penambangan emas terhadap kondisi tanah pada pertambangan rakyat Poboya Palu, Propinsi Sulawesi Tengah. *Jurnal Geomine*. 5(3):116-119.
- xxix. Wu, Y., Liu, T. and He, X., 2009. Mycorrhizal and dark septate endophytic fungi under the canopies of desert plants in Mu Us Sandy Land of China. *Frontiers of Agriculture in China*. 3(2): 164–170.
- xxx. Yang, A. N., Lu and N. Zhang. 2011. The diversity of arbuscular mycorrhizal fungi in the subtropical forest of Huangshan (Yellow Mountain), East- Central China. *World J. Microbiol. Biotechnol.* 27; 2351-2358.
- xxxi. 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(1): 352–369.