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Research Article

Effectiveness of mycorrhizae in tomato cultivation with nutrient stress levels in peat soil of West Kalimantan

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ABSTRACT

The growth and yield of tomatoes in peat soil with limited nutrient availability are expected to increase with the application of mycorrhizae, where mycorrhizae plays a role in the efficiency of fertilization in plants. This study aims to determine the effectiveness of arbuscular mycorrhizae fungi (AMF) obtained from peat land and alluvial soil ecosystems on the growth and yield of tomatoes at different levels of NPK nutrient in peat soil. The study was conducted using a completely randomized factorial design. The first factor was the type of soil source of AMF propagules (without AMF, AMF from peat land, and AMF from alluvial soil). The second factor was the dose of NPK fertilizer (100%, 75%, 50%, and 25% of NPK recommendation). The results showed that AMF propagule originating from peat land and alluvial soil stimulated the growth and yield of tomatoes on peat soil. The AMF propagules from peat land with 50% of NPK rekomendation dose effectively increased weight of single-fruit of tomato and weight of total tomato per plant.

Keywords: biofertilizer; mycorrhizae propagule; tomato production

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INTRODUCTION

Tomatoes (*Solanum lycopersicum* L.) is important horticultural commodity with the demand for Indonesian from 2019 to 2023 has increased, namely in 2019 (0.235 kg per capita year^{-1}), 2020 (0.236 kg per capita year^{-1}), 2021 (0.251 kg per capita year^{-1}), 2022 (0.250 kg per capita year^{-1}), and 2023 (0.250 kg per capita year^{-1}) (Kementerian Pertanian, 2023). The demand for tomatoes is not only as vegetable but is also as industrial purposes, of processed products and to cosmetic (Siregar et al., 2019). Tomatoes is source of Vitamin C, Vitamin A (carotene), and minerals (Wardana & Alzarliani, 2019; Fitriani et al., 2020; Ikawati et al., 2022). Tomatoes are also one of the most expensive horticultural commodities today. However, Indonesian tomato production is still low, 6.3 tons ha^{-1}, and still below the productivity in Taiwan, Saudi Arabia, and India with average production are 21 tons, 13.4 tons, and 9.5 tons ha^{-1}, respectively (Haikal et al., 2022).

Cultivating tomatoes on peatlands in West Kalimantan provides an opportunity to increase production because peatlands have a reasonably wide distribution, reaching 1.5 million hectares (BPS, 2019). However, peat land has fertility limitations due to very high C/N ratio, low pH, low base saturation, and low availability of macro and micronutrients (Aryanti et al., 2016; Siregar et al., 2021; Hidayat et al., 2022). Therefore, it is necessary to implement cultivation technology to support growth of tomato plants throught, applying arbuscular mycorrhizal fungi (AMF) as biofertilizers.

AMF external hyphae can broaden the root range for nutrients, and micro-sized AMF hyphae play a role in absorbing nutrients down to the smallest soil particles, which no longer can be done by root hairs (Basri, 2018). According to Mahmudi et al. (2023), AMF has a positive impact on increasing the ability of plants to absorb nutrients in the soil even in unfavorable conditions for plants. Regarding mycorrhiza's ability to support plant growth in conditions of nutrient stress, it is unclear which habitat AMF propagules can develop well, including the type of soil where the AMF host grows. Related to its presence in nature, AMF is cosmopolitan or easy to grow in any soil conditions (Nurhalimah et al., 2014). Therefore, a study is needed to determine the role of AMF in overcoming nutrient stress as well as compare AMF sourced from peat and alluvial soil types, which provide a positive contribution to the cultivation of tomato plants on peat media.

The study aimed to determine the effectiveness of AMF from peat soil and alluvial soil on the growth and yield of tomatoes at different levels of nutrient in peat soil.

MATERIALS AND METHODS

The initial research was implemented by taking AMF inoculum, namely in the rhizosphere of pineapple plants growing on peatlands located in Pontianak City and in dry land ecosystems with alluvial soil types located in Sanggau Regency. Peat and alluvial soil with mycorrhizae were taken at 0-20 cm from the soil surface and between plant roots. The total density of natural inoculum spores was ±107 spores per 50 g of peat soil and ±96 spores per 50 g of alluvial soil (results of analysis at the Plant Disease Laboratory of Tanjungpura University).

The research was conducted in Pontianak City, West Kalimantan, from May to September 2023. The planting media was prepared by cleaning the peat soil of roots and weeds and air-drying. The peat soil was put into polybags with a volume of 6 kg per polybag. Dolomite lime was given as much as 100 g per polybag, then the planting medium was incubated for two weeks. Tomato seeds were sown in three growing media (media without AMF, AMF from the peat soil, and AMF from the alluvial soil). The evaluation of AMF infection on roots 20 days after sowing. The evaluation was carried out in the Plant Disease Laboratory. Then, the tomato seedlings were transferred to the incubated peat media.

The arrangement of polybags in the field was carried out using a completely randomized factorial design. The first factor was AMF propagules (without AMF, AMF from peat soil, and AMF from alluvial soil). The second factor was the dose of NPK fertilizer (100%, 75%, 50%, and 25% of the recommended NPK dose). Recommendation dose was NPK fertilizer for peat soil following (Mugiyanto & Nugroho, 2000). The total number of treatment combinations was 12 with 3 replications. Each experimental unit consisted of 4 plants (3 non destructive samples and 1 destructive sample), so there were 144 observation units. The recommended doses of N, P, and K fertilizers for tomato are 92 kg N ha^{-1}, 90 kg P^2O_5 ha^{-1}, and 60 kg K_2O ha^{-1} (Mugiyanto & Nugroho, 2000). NPK was applied at 2 and 4 weeks after planting (WAP). Tomatoes were harvested when the fruit’s skin become red.

Plant heights were determined at 35 days after planting (DAP) by measuring from the base to the top growing point. The leaf number was calculated at 35 DAP. The dry weight of plant was measured from destructive sample at the age of 35 DAP and oven-dried at 90^oC for 2 x 24 hours. Fruit was collected from the first to the fifth harvest (starting at age 60 to 75 DAP). The fruit number was calculated by adding all the tomatoes harvested. The weight of single-fruit and weigh total fruit per plant were calculated. In addition, observations were made on the number of AMF spore densities in the planting media and root colonization at 35 DAP.

The data were processed with analysis of variance (ANOVA). Further tests were carried out on the results, which had a significant effect using the honestly significant difference test with a confidence level of 95%.

RESULTS AND DISCUSSION

Number of spores and root colonization due to AMF

In the media of plants at the maximum vegetative phase (35 DAP), the average spore density in the planting medium given AMF from the peat soil ecosystem was 55.7 units per 50 g of peat soil, while the spore density in the planting medium given AMF from the alluvial soil ecosystem was 47.0 units per 50 g of peat soil (Table 1). There is an indication that the peat soil was more suitable for AMF originating from peat soil than AMF originating from alluvial soil. Mycorrhizae spores will initially germinate and then form hyphae and apresotium on the root surface, which will ultimately result in infection of the plant roots (Basri, 2018). The form of mycorrhizae spores and AMF colonization on tomato roots after being observed microscopically can be seen in Figure 1.

Table 1. The number of spores and root infections of tomato plants due to AMF.

AMF propagules	NPK level (% recommended)	Number of spores (unit per 50 g peat soil)	Root infections by AMF (%)
AMF peat soil	100	30	58
	75	52	67
	50	72	75
	25	69	70
Average		55.7	67.5
AMF alluvial soil	100	28	45
	75	42	56
	50	51	68
	25	67	62
Average		47.0	57.7

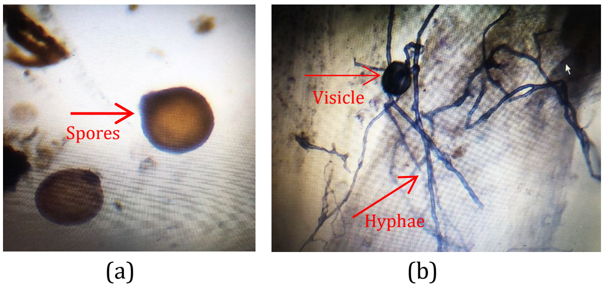


Figure 1. Mycorrhizae spores in the planting media (a) and AMF infection on tomato roots (b).

The AMF colonization in roots decreased with the higher dose of NPK fertilizer, and the occurrence of AMF colonization on tomato roots was the highest when combined with NPK 50% of the NPK recommended dose. The average percentage of AMF colonization on tomato roots due to AMF from peat ecosystems ranges from 58-75%, while the average AMF colonization from alluvial soil ecosystems ranges from 45-68% (Table 1). According to Buba and Muhammad (2020), one of the factors determining the level of AMF colonization of plant roots is the nutrient status of the soil. The soil with low nutrients is more optimal for AMF colonizing plant roots (Asmarahman et al., 2018; Budi & Dewi, 2016).

Plant height

The results showed the interaction of AMF propagules and NPK fertilizer doses significantly affected plant height (Table 2). The results of the HSD test showed that the height of tomato plants in the interaction of AMF from peat soil with 50% NPK dose was significantly higher compared to other treatments, but it did not differ from the plant height in the interaction of AMF from peat ecosystems and 25% NPK fertilization of the recommended dose and the interaction of AMF from alluvial ecosystems with 50% NPK fertilization of the recommended dose (Table 2).

Table 2. The plant height, leaf number, plant dry weight, on the interaction of AMF propagules and NPK fertilizer.

AMF propagules	NPK dosage (% recommended)	Plant height (cm)	Leaf number	Plant dry weight (g)
Without AMF	100	70.2d	100.7cd	30.2d
	75	68.0de	99.2cd	28.0de
	50	65.1e	98.7de	25.1e
	25	63.2e	96.9e	23.2e
AMF peat soil	100	88.1bc	103.0ab	48.1bc
	75	90.0b	103.5ab	50.0b
	50	95.1a	105.1a	55.1a
	25	92.2ab	103.7ab	52.2ab
AMF alluvial soil	100	84.9c	102.4bc	44.9c
	75	88.1bc	102.9abc	48.1bc
	50	90.7ab	104.1ab	50.7ab
	25	88.9bc	103.0ab	48.9bc
HSD 5%		4.8	2.5	4.8

Note: Numbers in column followed by the same letters are not significantly different based on the HSD test at the 5% level.

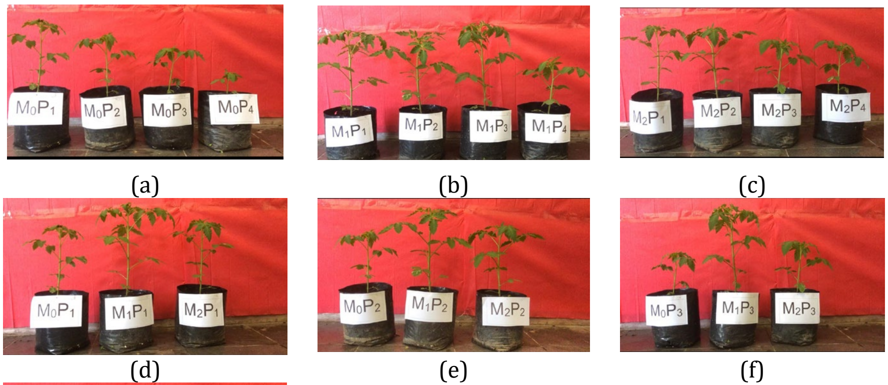
During the growth phase, the AMF treatment from both peat soil and alluvial soil ecosystems increased plant height and leaf number at all levels of NPK fertilization compared to plants without AMF (Table 2). The performance of plant growth is presented in Figure 2. It can be seen that reducing the dose of NPK fertilizer caused a decrease in plant height in the treatment without AMF. Conversely, plants colonized by mycorrhizae, reducing the dose of NPK fertilizer applied did not reduce plant height. AMF increase plant growth, and when given less NPK fertilizer, AMF will function more efficiently (Fasusi et al., 2021; Elekhtyar et al., 2022; Felföldi et al., 2022; Khan et al., 2022). AMF can help the absorption of N, P, K, and other nutrients (Shao et al., 2021; Zai et al., 2021)

Leaf number

The leaf number was significantly influenced by the interaction of AMF propagules and NPK fertilizer doses (Table 2). HSD test showed that the number of tomato leaves obtained in the interaction of AMF from the peat ecosystem with 50% NPK fertilizer from the recommended dose was significantly higher than that of other interactions. Still, it did not differ compared to the leaf number in the interaction of AMF from the peat ecosystem with 100%, 75%, and 25% NPK fertilization from the recommended dose, as well as the leaf number in the interaction of AMF from the alluvial ecosystem with 75%, 50%, and 25% NPK fertilization (Table 2). Therefore, to produce a high leaf number on mycorrhizae colonized tomato plants, it is sufficient to provide the recommended 25% NPK dose, both AMF from peat soil ecosystems and AMF from alluvial soil. Mycorrhizae can work effectively in planting media with limited nutrient conditions (El-Fattah et al., 2021; Shankar et al., 2021; Elekhtyar et al., 2022).

Plant dry weight

The interaction of AMF propagules and NPK fertilizer dosage significantly influenced the dry weight of tomato plants. The HSD test results revealed that the dry weight of plants in the interaction of AMF from peat ecosystems with 50% NPK fertilization of the recommended dose was significantly higher than that of plants in other interactions. However, it did not differ from the dry weight in the interaction of AMF from peat ecosystems and 25% NPK fertilization of the recommended dose and the interaction of AMF from alluvial ecosystems with 50% NPK fertilization of the recommended dose (Table 2).



Note: M0, M1, M2 = Without AMF, AMF propagules from peat ecosystems, AMF propagule from alluvial soil ecosystems; P1, P2, P3, P4 = NPK fertilizer of 100%, 75%, 50%, 25% recommended dosage.

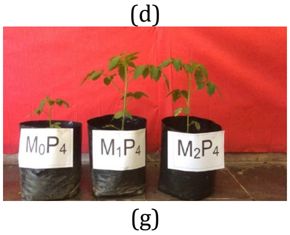


Figure 2. Growth performance of tomato plants in various treatments: (a) Without AMF at various NPK dose levels of 100, 75, 50, and 25% (b) The AMF from peat soil at various NPK dosage levels of 100, 75, 50, and 25% (c) The AMF from alluvial soil at various NPK dosage levels of 100, 75, 50, and 25% (d) Without AMF, peat soil ecosystems AMF, and the AMF from alluvial soil at 100% NPK dosage (e) Without AMF, peat soil ecosystems AMF, and the AMF from alluvial soil at 75% NPK dosage (f) Without AMF, peat soil ecosystems AMF, and the AMF from alluvial soil at 50% NPK dosage (g) Without AMF, peat soil ecosystems AMF, and the AMF from alluvial soil at 25% NPK dosage.

The results related to the role of AMF as a plant growth promoter through the effectiveness of the plant root system in optimizing the absorption of more nutrients in the soil, primarily N and P nutrients (Astiko et al., 2019). These nutrients will be helpful as raw materials for the process of photosynthesis, which will ultimately maximize the process of cell division and enlargement in plants and increase plant biomass. According to Wicaksono et al. (2014), mycorrhizae can raise plant dry matter.

Fruit number

Each AMF propagule treatment and NPK fertilizer dose significantly influenced the fruit number of tomato. The results of the HSD test showed the plants that were colonized with mycorrhizae, both AMF from peat soil and from alluvial soil, had significantly more tomato fruits than plants that were without mycorrhizae. The fruit number of tomato when using an NPK fertilizer of 50% of the recommended dose is significantly greater than when using a dose of 100% and 25% of the recommended dose, but is not different when using an NPK fertilizer of 75% of the recommended dose (Table 3).

According to Prayudyaningsih (2014), the AMF can help root development in the rhizosphere and increase the uptake of P nutrients and other nutrients such as N, K, Zn, Co, S, and Mo from the soil, where these elements are really needed by plants for growth and development, especially the P nutrient required for flowering and fruit formation. According to Safei et al. (2014), the P element for plants is needed for the process of assimilation and respiration and plays a role in accelerating plant flowering and fruiting.

Table 3. The fruit number of tomatoes for each treatment with AMF propagules and NPK fertilizer.

AMF propagules	Fruit number of tomatoes
Without AMF	22.3b
AMF peat land	35.1a
AMF alluvial soil	32.7a
HSD 5%	3.3
NPK dosage (% recommended)	Fruit number of tomatoes
100	29.7b
75	30.7ab
50	34.7a
25	25.1c
HSD 5%	4.2

Note: Numbers followed by the same letter are not significantly different based on the HSD test at the 5% level.

Fruit weight

The weight of single fruit and total fruit of tomatoes per plant were significantly influenced by the interaction of AMF propagules and NPK fertilizer dosage. The weight of single fruit from the interaction of AMF from peat ecosystems and 50% NPK fertilization was significantly heavier than that from other treatments. However, there was no difference in the weight of single fruit from the interaction of AMF from peat ecosystems and 75% NPK fertilization of the recommended dose, and the interaction of AMF from alluvial ecosystems at 50% NPK fertilization of the recommended dose (Table 4).

The weight of total fruit per plant with the interaction of AMF from peat ecosystems and 50% NPK fertilization was significantly heavier than those from other treatment interactions. However, there was no significant difference compared to the weight of total fruit per plant with the interaction of AMF from alluvial ecosystems and 50% NPK fertilization from the recommended dose (Table 4).

Improvements in the growth of plants colonized by mycorrhizae were also accompanied by plant yield components in the form of increases in the weight of single fruit and total fruit of tomato per plant. According to Murtilaksono et al. (2020), root colonization due to AMF will create a network of external hyphae and directly affect the ability of the roots to absorb water and nutrients, thereby increasing fertilization efficiency. In conditions of limited nutrient availability, AMF will be more effective in helping plant roots absorb macro- and micronutrients in the soil, ultimately supporting more optimal plant metabolic processes. According to Yusuf et al. (2017), there was an increase in generative components and plant yields related to the phosphorus element absorbed by plants for disposal, fertilization, and seed formation, even being able to speed up fruit ripening and make the seeds heavier.

Table 4. Weight of single fruit and weight of total tomato fruit per plant on the interaction of AMF propagules and NPK fertilizer.

AMF propagules	NPK dosage (% recommended)	Weight of single tomato fruit (g)	Weight of total tomato fruit per plant (g)
Without AMF	100	41.5c	1,038.8de
	75	39.4cd	961.9e
	50	34.5d	780.0e
	25	33.2d	579.9e
AMF peat land	100	59.8b	2,000.6bc
	75	60.6ab	2,128.4bc
	50	66.8a	2,790.1a
	25	59.4b	1,797.7c
AMF alluvial soil	100	57.8b	1,771.0c
	75	59.7b	1,958.3bc
	50	62.8ab	2,496.5ab
	25	57.4b	1,596.2cd
HSD 5%		4.8	4.8

Note: Numbers followed by the same letter in the same column are not significantly different based on the HSD test at the 5% level.

CONCLUSIONS

AMF propagule originating from peat land and alluvial soil increased the growth and yield of tomatoes growing on peat soil. The combination of AMF from peat land with 50% NPK recommendation dose increased the production of tomato plants based on the variables weight of single fruit of tomato and weight of total tomato fruit per plant.

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