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Growth and Production Response of Cayenne Pepper to Phosphate-Solubilizing Bacteria (BPF) and Arbuscular Mycorrhizal Fungi (FMA) in Alfisol Soil in Tuban Regency

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ABSTRACT

The majority of Tuban Regency is predominantly low fertility alfisol soil with low P nutrient availability for plants. Therefore, it requires BPF to convert insoluble phosphate into available P, supported by the application of FMA to maximize nutrient uptake through the hyphae formed on chili plant roots. This study aims to determine the growth response of cayenne pepper when applied with BPF and FMA planted in alfisol soil. The research used a randomized block design (RBD) with 8 treatments replicated 3 times, resulting in a total of 24 experimental plots. The treatments include Control; P Fertilizer; BPF; FMA; P Fertilizer + BPF; P Fertilizer + FMA; BPF + FMA; and P Fertilizer + BPF + FMA. The observed plant growth parameters include flowering time, growth vigor, plant height, leaf count, and stem diameter measured at the onset of flowering and early harvest. The results showed that the application of BPF and FMA, individually or in combination, was able to enhance the growth of cayenne pepper plants. The best treatment in this study was P Fertilizer + BPF + FMA with the respective average parameters such as flowering time of 48.333 days after planting (DAP), growth vigor of 1.000, plant height at the onset of flowering of 51.750 cm and at early harvest 60.500 cm, leaf count at the onset of flowering of 57.333 leaves and at early harvest 115.333 leaves, and stem diameter at the onset of flowering of 8.1833 cm and 12.3000 cm at early harvest.

Keywords: *Cayenne Pepper, Biological Agents, Fertilization, Growth*, *Land Improvement*

1. INTRODUCTION

The agricultural sector is the mainstay of the Indonesian economy, encompassing staple crops, horticulture, and ornamental plants. Horticultural products are promising commodities to meet domestic market needs (Yuliatiningsih, et al. 2022). One of the horticultural plants serving as an export commodity and the main ingredient for household, industrial, and restaurant needs is this chili (Capsicum frutescens L.) (Polii et al. 2019). Due to the importance of Cayenne Pepper chili in various sectors, there is a need to increase its production to meet demand. However, in reality, in some chili-producing areas, production remains fluctuating, highlighting the necessity for technological advancements. Decreases in production can be attributed to unpredictable nutrition and climate factors, posing challenges for Cayenne Pepper chili farmers, especially in Tuban Regency.

Tuban Regency is one of the regions in the province of East Java that has contributed to the production of Cayenne Pepper chili. The Cayenne Pepper chili plantations in Tuban Regency cover an area of 7245 hectares; however, the production of Cayenne Pepper chili fluctuates annually. In 2021, the Cayenne Pepper chili production in Tuban Regency reached 567,278 kW, while in 2022, it decreased to 366,783 kW (Muzadi and Rastono, 2023). Calculating the decrease in Cayenne Pepper chili production in Tuban Regency amounts to 200,495 kW.

The majority of Tuban Regency is covered by alfisol soil originating from limestone with Typic Eutrudepts type, having a pH of 6.8-8.1, and high clay content (Prasetyo, 2009). Alfisol soil is characterized by deep soil profile, porous structure, and good drainage supporting plant root growth (Fajeriana and Gafur, 2023). However, alfisol soil often faces challenges related to clay Cation Exchange Capacity (CEC), base saturation, soil pH, and phosphorus nutrient retention (Yudha et al., 2014). When applying phosphorus fertilizers, a significant portion may be immobilized by the soil, limiting its availability to plants (Zhou et al., 2022), hence the requirement for phosphate-solubilizing bacteria (PSB) to enhance phosphorus uptake. Another growth-limiting factor for plants is environmental uncertainties like temperature and water availability (Azhari et al., 2023). High temperatures lead to water loss due to evaporation from the soil, causing water deficits for plants, highlighting the importance of arbuscular mycorrhizal fungi (AMF) application.

During the dry season in the Tuban Regency, the air temperature reaches 39°C, with soil temperature at 32%, air humidity at 35%, and soil moisture at 45%, which are considered less than ideal for agricultural land use (Muzadi and Rastono, 2023). Phosphate-solubilizing bacteria and arbuscular mycorrhizal fungi working together can increase soil moisture, lower soil temperature, and strengthen micro and macro aggregates (Syamsiyah et al., 2023). This is consistent with a study by Rahman (2019), stating that FMA application can enhance BPF populations, maximizing phosphorus elements for chili plants. These findings form the basis for further research to investigate the influence of BPF and FMA on Cayenne Pepper chili in Tuban Regency. The total phosphorus nutrient status in alfisol land in Tuban Regency is relatively high, ranging from 36-86 µg/g P, creating opportunities for plant utilization if it can be converted into available phosphorus for plants (Wiesmeier et al., 2015).

Phosphate-solubilizing bacteria not only convert insoluble phosphate by secreting organic acids to make P available to plants but also produce exopolysaccharide compounds that can bind soil particles to enhance soil water retention. Arbuscular mycorrhizal fungi can symbiotically interact through hyphae

growing on plant roots to improve plant resistance to drought, increase nutrient absorption, and enhance disease resistance throughout various seasons. Given these phenomena, research is needed on the combination of phosphate-solubilizing bacteria and arbuscular mycorrhizal fungi to support Cayenne Pepper chili production in Tuban Regency.

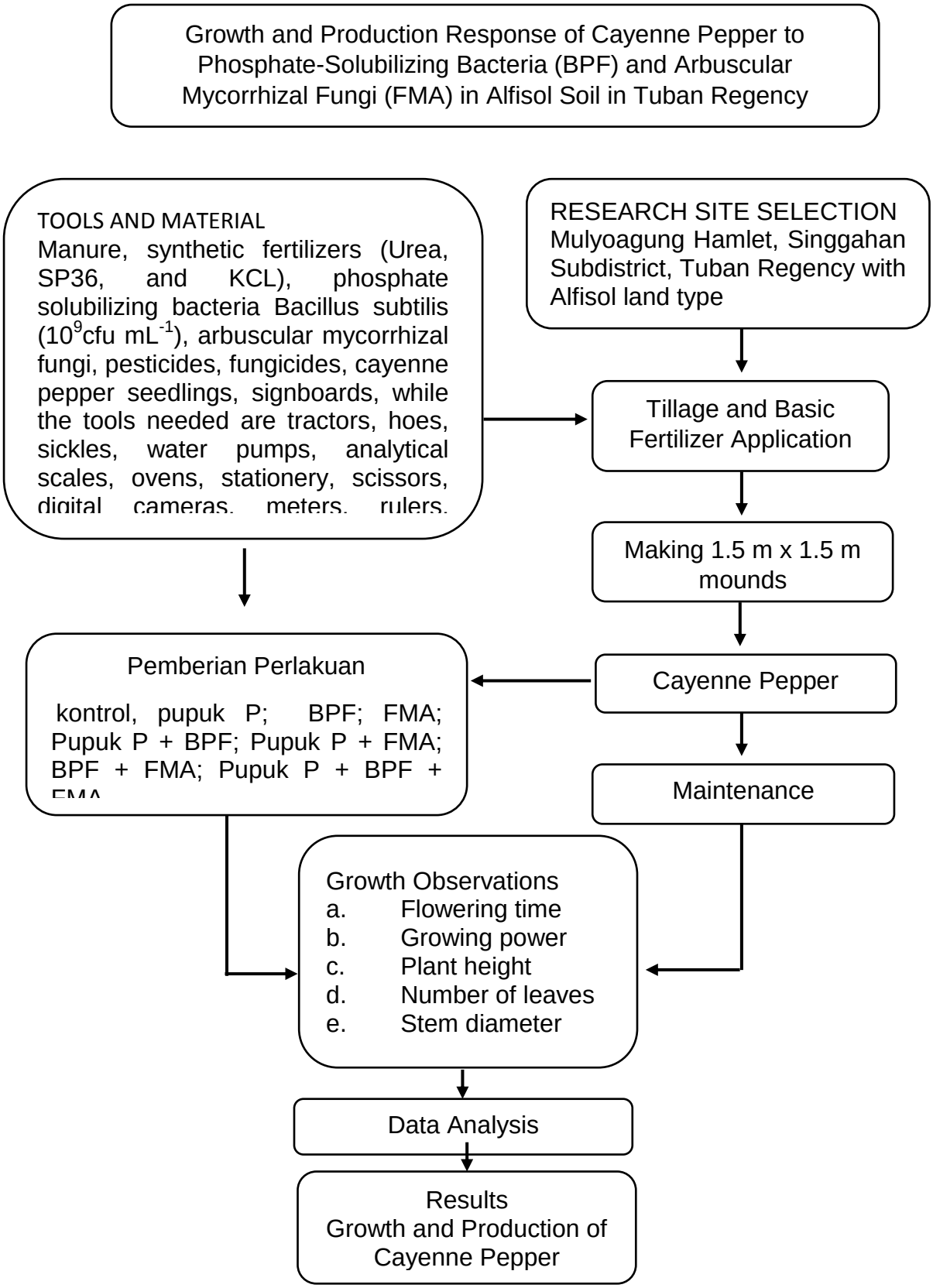
2. MATERIAL AND METHODS

This research was conducted between June and September 2023 in Mulyoagung Village, Singgahan District, Tuban Regency, East Java. The area is situated between Latitude 6°57'55.1"S and Longitude 111°47'23.2"E. Mulyoagung Village has an elevation of 47 meters above sea level and is approximately 60 km away from the city center of Tuban.

The materials used in this research include a land area of 300m2, manure, synthetic fertilizers (Urea, SP36, and KCL), phosphate solubilizing bacteria Bacillus subtilis (109cfu mL-1), arbuscular mycorrhizal fungi, pesticides, fungicides, Cayenne Pepper chili seeds, signboards. The required tools include a tractor, hoe, sickle, water pump, analytical balance, oven, writing tools, scissors, digital camera, meter, ruler, callipers, and hand sprayer.

This research utilized a randomized complete block design (RCBD) with 8 treatments repeated 3 times, resulting in a total of 24 experimental plots. The treatments included the application of 300kg SP36/ha of fertilizer P, followed by the phosphate-solubilizing bacterium Bacillus subtilis (109cfu mL-1), and the application of arbuscular mycorrhizal fungi at a rate of 10 grams per plant. The treatments to be implemented in the study are as follows: control, P fertilizer; BPF; FMA; P fertilizer + BPF; P fertilizer + FMA; BPF + FMA; P fertilizer + BPF + FMA.

The initial step in conducting the research is to prepare a 300m2 land area to improve the soil structure. Subsequently, organic fertilizer is applied at a rate of 30 tons/ha. The prepared land is then formed into mounds measuring 1.5m x 1.5m with a spacing of 50 cm between each plot, left to settle for 2 weeks to prepare it for planting. Chili peppers are planted with hole intervals of 70 x 50 cm (Litbang, 2019). Daily watering is done in the morning until harvest. Pest and disease management are carried out if symptoms appear. Phosphorus, BPF, and AMF fertilizers are jointly applied at the beginning of planting by irrigating around the planting holes in accordance with the research design.



The growth parameters of cayenne pepper plants that will be observed include:

a. Flowering time

This variable is observed every 3 days starting from 45 to 50 DAP. Flowering time is determined when the number of plants that flower is more than 50%.

b. Growing power

Growth capacity was calculated at 14 DAP based on the percentage of plants that grew.

c. Plant Growth

Measurement of plant growth includes plant height, number of leaves, and stem diamater observed at the beginning of flowering and the beginning of harvest.

Data from parameter observations were collected and then analyzed using analysis of variance (Anova), if there was a real effect, then continued the DMRT test at the 5% level. The research procedure if outlined in a flow chart is as follows:

3. RESULT AND DISCUSSION

a. Flowering Time

Flowering is a crucial physiological process linked to the existence of plants. The timing of flowering determines the timing of fruiting and the harvest yield. Plant growth and development, particularly flowering, depend on the interaction between complex processes influenced by genetics and the environment. The speed or slowness of flowering time can be associated with the plant's acclimatization and its ability to withstand environmental disturbances or support. The observed flowering times are presented in Table 1.

Table 1. Flowering Time Observations

Treatment	Flowering Time (DAP)
(Control)	70.00±4.36[a]
(P. Fertilizer)	67.00±0[a]
(BPF)	56.33±2.89[bc]
(FMA)	53.33±2.89[c]
(P. Fertilizer+BPF)	56.67±2.89[bc]
(P. Fertilizer +FMA)	51.00±1.73[c]
(BPF+FMA)	50.00±2.00[c]
(P. Fertilizer +BPF+FMA)	48.33±3.51[d]

Note: 1. The higher the average number of days to flowering, the longer the flowering time, and the smaller the average number of days to flowering, the faster the flowering time.
2. Column numbers followed by the same letter are not significantly different (P>0.05) in the 5% BNT test.

The results of the variance test in Table 1 show that the control and P fertilizer treatments are significantly different from the BPF; FMA; P + BPF; P + FMA; BPF + FMA; P + BPF + FMA. The treatment of P Fertilizer + BPF + FMA is significantly different from all treatments. The results were not significantly different between the control treatment with P fertilizer, then the BPF treatment; FMA; P fertilizer + BPF; P fertilizer + FMA; BPF + FMA. The longest average flowering time was shown in the control treatment with a flowering time of 70,000 DAP and P fertilizer treatment for 67,000 DAP. The treatment of P Fertilizer + BPF + FMA showed a significant difference between all treatments with the fastest flowering time of 48,333 DAP.

It is known that Tuban district has alfisol-type soil with a saturated base character which results in low P elements (Muzadi and Rastono 2023) The application of P fertilizer to cayenne pepper may not be absorbed quickly due to the slow release nature of P fertilizer which results in a late flowering process (Rahman, 2019). In addition, in cayenne pepper plants in drought stress in the dry season the transpiration rate is reduced to avoid water loss so that the narrowing or closing of stomata will inhibit flowering time (Yuniati and Safrudin 2019).

The treatments of BPF; FMA; P+BPF fertilizer; P+FMA fertilizer; and

BPF+FMA, were not significantly different so it can be said that the application of BPF and FMA independently or in combination was able to increase the acceleration of flowering. BPF and FMA applied independently can symbiotically with the basic fertilizer used in this study, namely manure. BPF symbiosis will help P elements become available so that they are easily absorbed by plants (Sabrina et al. 2020), while FMA is able to improve soil fertility levels so that macro essential nutrients such as N and P become increased and available to plants (Nurmastiyah, et al., 2013). This follows the results of research by Asih and Wartapa (2022), which states that phosphate solubilizing bacteria + FMA applied to peanut plants can increase the number of filled pods, reduce the number of cipo pods and increase the vigor index better than the control. So that if P+BPF+FMA fertilizer is combined, it will maximize generative development in plants such as flowering time.

b. Growing Power

Cayenne pepper is able to grow well when climatic conditions with 10-12 hours of irradiation, optimal temperature of 24°C-30ºC, soil and air humidity around 66% - 80% (Hariri et al., 2019). This statement does not follow the results of the research that has been done. This research was conducted in the dry season so that the average ambient temperature reached 39 ° C with air humidity up to 35%. This situation will trigger planting the land with alfisol soil types to dry quickly because it is easy to absorb and lose water (Fajeriana and Gafur 2023). The results of observations of the growing power of chili plants at 14 DAP are shown in Table 2 below:

Table 2. Growing Power Observation

Treatment	14 DAP (%)
(Control)	0.50 ± 0.35^{c}
(P. Fertilizer)	0.63 ± 0.21^{c}
(BPF)	0.77 ± 0.27^{ab}
(FMA)	1.00 ± 0^{a}
(P. Fertilizer+BPF)	0.77 ± 0.14^{ab}
(P. Fertilizer +FMA)	0.94 ± 0.14^{a}
(BPF+FMA)	1.00 ± 0^{a}
(P. Ferilizer+BPF+FMA)	1.00 ± 0^{a}

Note. 1. The number of growth power after 14 DAP < 1 indicates that the chili plants did not grow 100%.
2. The numbers in the same column followed by the same letter are not significantly different (P>0.05) in the 5% BNT test.

Based on the results of the analysis of variance showed a significant difference. The control treatment and P fertilizer showed the smallest value and were not significantly different, but the control treatment and P fertilizer were significantly different from the BPF treatment; FMA; P+BPF fertilizer; P+FMA fertilizer; BPF+FMA; and P+BPF+FMA fertilizer. The control treatment and P fertilizer showed low growth capacity of chili plants, namely control of 0.5033 and P fertilizer of 0.6300. High light intensity affects the temperature of the research area up to 32°C and soil moisture of 45% caused by transpiration and evaporation. Water plays a role in cell turgidity so that if plants lack water it will inhibit cell growth (Saputra and Amien 2022).

BPF treatment with a growing power of 0.7767 and P+BPF fertilizer of 0.7700, shows that in addition to being able to dissolve P elements, BPF is able to stabilize aggregates, improve soil structure, water holding power, so that the soil becomes loose so that plant roots are able to absorb nutrients, but it will be more optimal when combined with

mycorrhiza (Birnadi 2012). Maximum plant growth power is shown in the FMA, BPF + FMA and P + BPF + FMA fertilizer treatments with a growth power value of 1.0000, meaning that all plants did not die. Arbuscular Mycorrhizal Fungi are able to increase the resistance of host plants to drought conditions by forming hyphae in the root area to make it easier for plants to absorb nutrients (Asih and Wartapa 2022). In line with Rahman's research, (2019) which states that the provision of FMA can increase the BPF population so that the uptake of available P elements can help the growth and production of chili peppers.

c. Plant Growth (Plant Height, Number of Leaves, and Stem Diameter)

Plant growth is indicated by the increase in plant dimensions both in height and diameter and the number of leaves. The height of the cayenne pepper plant is measured from the base of the stem to the end of the stem, the diameter of the stem is measured using a sliding bar (calliper) and measured at a height of about one cm above the base of the stem. Then the number of leaves is counted entirely. Growth observation data are shown in Table 3, Table 4, and Table 5 below.

Table 3. Variety Test Results of Cayenne Pepper Plant Height

Treatment	Plant Height (cm)	
	Starting to Flower	Starting to harvest
(Control)	33.33±10.48^{b}	36.17±9.31^{c}
(P. Fertilizer)	34.33±11.78^{b}	37.33±11.78^{c}
(BPF)	48.33±7.07^{a}	52.33±8.01^{ab}
(FMA)	45.17±2.59^{a}	49.67±2.36^{b}
(P. Fertilizer+BPF)	44.83±1.77^{a}	48.00±3.30^{b}
(P. Fertilizer +FMA)	45.50±1.18^{a}	50.67±0.94^{b}
(BPF+FMA)	47.83±3.06^{a}	55.50±2.47^{ab}
(P. Ferilizer+BPF+FMA)	51.75±5.53^{a}	60.50±4.01^{a}

Note: The numbers in the same column followed by the same letter are not significantly different (P>0.05) in the 5% BNT test.

Table 4. Variety Test Results of Number of Cayenne Pepper Leaves

Treatment	Number of Leaves	
	Starting to Flower	Starting to harvest
(Control)	29.00±15.08^{b}	41.33±11.90^{c}
(P. Fertilizer)	27.00±9.42^{b}	48.83±12.96^{c}
(BPF)	57.16±17.20^{a}	99.17±17.20^{b}
(FMA)	47.00±5.65^{a}	88.67±5.18^{b}
(P. Fertilizer+BPF)	46.83±0.70^{a}	88.83±0.70^{b}
(P. Fertilizer +FMA)	46.33±2.35^{a}	89.33±2.35^{b}
(BPF+FMA)	48.00±10.25^{a}	99.00±10.25^{b}
(P. Ferilizer+BPF+FMA)	57.33±16.49^{a}	115.33±16.49^{a}

Note: The numbers in the same column followed by the same letter are not significantly different (P>0.05) in the 5% BNT test.

Table 5. Variety Test Results of Stem Diameter of Cayenne Pepper

Treatment	Stem Diameter	
	Starting to Flower	Starting to harvest
(Control)	5.57±1.50[c]	6.70±0.53[c]
(P. Fertilizer)	6.57±0.84[c]	7.50±0.70[c]
(BPF)	7.45±0.96[ab]	9.25±1.29[b]
(FMA)	7.57±0.14[ab]	9.17±0.00[b]
(P. Fertilizer+BPF)	7.25±0.42[ab]	9.25±1.19[b]
(P. Fertilizer +FMA)	7.15±0.21[ab]	9.37±1.37[b]
(BPF+FMA)	7.11±0.82[ab]	9.85±0.07[b]
(P. Ferilizer+BPF+FMA)	8.18±0.49[a]	12.30±0.89[a]

Note: The numbers in the same column followed by the same letter are not significantly different (P>0.05) in the 5% BNT test

The results of the variance test for the parameters of plant height, number of leaves and stem diameter of cayenne pepper at the beginning of flowering and early harvest showed that the control treatment and P fertilizer were not significantly different, but these two treatments were significantly different from the BPF treatment; FMA; P+BPF fertilizer; P+FMA fertilizer; BPF+FMA; and P+BPF+FMA fertilizer. in all measurement parameters.

The control treatment where no P fertilizer or biological agent was applied so that the average results of the variance test in all growth measurement parameters had low values (Table 3). This condition occurs because plants rely on organic matter in the form of manure given during tillage as a source of nutrients. Organic matter applied to alfisol land has not fully maintained drought stress conditions (Muzadi and Rastono 2023). Increased drought disrupts growth phases such as physiology and morphology due to lack of water, not optimal nutrient uptake, and high transpiration and evaporation.

P fertilizer treatment also showed poor results so the results were not significantly different from the control in all growth parameters. P fertilizer is a fertilizer that is difficult to be absorbed by plants because it is not easily soluble in water. Sub-optimal land such as alfisol soil has great potential as agricultural land because it still has potential nutrients, one of which is the element P, but in alkaline soil, the element phosphate (P) will bind to calcium (Ca) to form Ca-P which is difficult to dissolve, so that its form is not available to plants (Ilham et al. 2014). Element P is an important component of compounds for energy transfer, lack of element P will cause the development of plant roots to be inhibited and plants become stunted (Joice et al., 2022).

Based on Table 3, it can be observed that the application of BPF and FMA either in combination or independently is capable of enhancing plant height, leaf count, and stem diameter at the beginning of flowering, except for the control treatment and P fertilizer, despite the variance analysis results showing no significant difference. On the other hand, the average results of measuring the parameters of leaf count and stem diameter at the initial harvest indicate that the P+BPF+FMA treatment significantly differs at a 5% significance level from all other treatments, with an average leaf count of 115.333 leaves and an average stem diameter of 12.300 cm. In terms of plant height parameters, all treatments except for the control and P fertilizer at the initial harvest do not show a significant difference; however, the P+BPF+FMA treatment has a significantly greater average plant height of 60.500 cm.

The growth of Cayenne Pepper chili plants with the application of BPF

and FMA can thrive well. The BPF applied to Cayenne Pepper chili plants in alfisol soil functions to reduce the inefficiency of phosphate fertilizer usage by breaking down Al or Fe hydroxide compounds that bind phosphate to reduce inorganic phosphate fixation (Karti et al, 2013). The increase in phosphorus content and uptake in plants by BPF is achieved by releasing oxalate and acetate acid exudates. According to (Suryatmana, et al.2022), plants utilize phosphorus in the embryonic cell division from the apical meristem for plant height growth, and then phosphorus can stabilize metabolism to increase stem diameter through lateral meristem cell division. The nutrient that determines leaf quantity in Cayenne Pepper chili plants is nitrogen, hence in the Control treatment and phosphate fertilizers, the number of leaves is low. However, with the BPF treatment and P+BPF fertilizer, the leaf quantity can still increase. This result is consistent with the study by Lovitna et al., (2021) which indicates that the application of BPF and inorganic phosphate fertilizers significantly affects the number of leaves at 2 weeks after planting.

The use of FMA inoculation can enhance the uptake of P nutrients in plants due to the hyphae formed by FMA. Mycorrhizal plants can improve the absorption of nutrients such as N, P, K, Ca, and Mg, thereby promoting the growth and production of Cayenne Pepper chili peppers (Rahman et al., 2019). Cayenne Pepper chili plants treated with FMA, P fertilizer+FMA, compost+FMA, and P fertilizer+compost+FMA showed increased plant height, leaf number, and stem diameter during the early flowering and early harvesting stages. The application of FMA not only enhances nutrient uptake but also improves resistance to drought by enhancing water absorption through the combined root and mycorrhizal system. Additionally, mycorrhiza can produce phosphatase enzymes that work to release fixed phosphorus nutrients in the soil, making it available for plant roots (Anggiani et al., 2021).

The application of AMF on Cayenne Pepper chili plants can establish colonies in the roots and improve soil aeration to support beneficial soil microorganisms' activities. Moreover, it will activate the soil food web indirectly enhancing the organic matter needed for soil bacteria's life. The evidence from the treatment of beneficial soil microorganisms and AMF can be observed based on the root morphology presented in figure 1 for each treatment below.

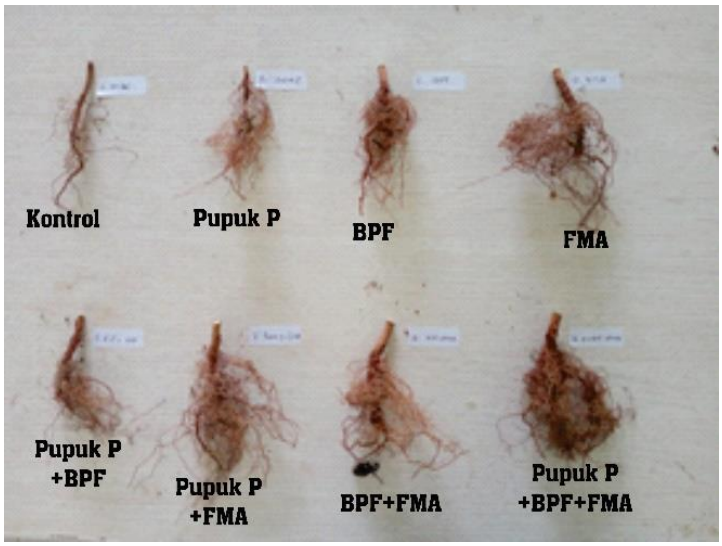


Figure 1. Cayenne pepper roots in each treatment

The BPF living in the rhizosphere and hyphosphere also help AMF make unavailable P available and absorbed directly by plants through hyphae. The treatment of P+BPF+AMF given to Cayenne Pepper chili plants showed an increased growth rate in plant height, number of leaves, and stem diameter at the early flowering and early harvest stages. The combined application of AMF and BPF is able to interact positively, and BPF has a longer lifespan (Rahman et al., 2019). This research is consistent with a study conducted by Muzadi and Rastono (2023) showing that the application of P, BPF, and AMF together can increase plant height, number of leaves, and stem diameter at 35 DAP.

4. CONCLUSION

The independent or combined application of BPF and FMA can enhance the growth of Cayenne Pepper chili plants. In this study, the best treatment was the application of P+BPF+FMA fertilizer with average parameters such as flowering time of 48.333 days after planting, growth power with a quantity of 1,000, plant height at the beginning of flowering at 51.750 cm and at harvest at 60.500 cm, the number of leaves at the beginning of flowering at 57.333 and at harvest at 115.333, and stem diameter at the beginning of flowering at 8.1833 cm and 12.3000 cm.

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