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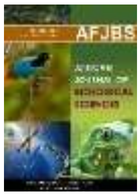

INFLUENCE OF PLANT GROWTH PROMOTING RHIZOBACTERIA ON CHILI PEPPER (*Capsicum frutescens*) IN MONOCULTURE AND INTERCROPPING SYSTEMS

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ABSTRACT

This study aims to evaluate the influence of Plant Growth Promoting Rhizobacteria (PGPR) on chili pepper (*Capsicum frutescens*) in monoculture and intercropping systems. PGPR are microorganisms that can enhance plant growth through nitrogen fixation, phosphate solubilization, and hormone production. The study was conducted at the Fruit and Vegetable Garden in Kampung Pelangi, Malang, using a nested design with two factors: PGPR concentration (0, 10, 20, and 30 ml/l) and planting system (monoculture and intercropping with papaya). The results showed that monoculture systems and increased PGPR concentrations significantly improved plant height, leaf number, leaf area, crop growth rate, fruit number, fruit weight, and yield. Monoculture with a PGPR concentration of 30 ml/l produced the best growth and yield. These findings suggest that PGPR application and monoculture planting systems can significantly enhance chili pepper productivity.

Keywords: PGPR, chili pepper, intercropping, nitrogen fixation, phosphate solubilization, hormone production.

INTRODUCTION

Chili pepper (*Capsicum frutescens*) are a significant vegetable commodity in Indonesia, essential for daily consumption. According to Howard, Talcott, Brenes, and Villalon (2000), chili peppers have high economic value and contain compounds such as capsaicin, ascorbic acid, carotenoids, essential oils, resins, flavonoids, and vitamin C, which is higher than red peppers. Indonesian society, especially teenagers, favor chili peppers for their spicy flavor. Chili peppers are used as a kitchen spice, a primary ingredient in the sauce industry, and the pharmaceutical industry. The demand for chili peppers in Indonesia is high, approximately 4 kg/capita/year (Warisno, 2010; Wahyudi et al., 2023).

The growth rate of chili pepper farmers has been increasing annually, with national production rising from 1,335,608.00 tons in 2018 to 1,374,217.00 tons in 2019 and 1,508,404.00 tons in 2020 (BPS, 2021). The prospects for chili pepper vegetables are promising for domestic and export markets. However, productivity and land ownership among farmers have declined. Increasing chili pepper production using chemical fertilizers can harm the environment, causing soil degradation and pest disturbances without organic materials. With limited land availability, appropriate cultivation techniques are needed to enhance land productivity, reduce harvest failure risks, and increase crop yields.

To address these issues, chili pepper production should be increased using organic fertilizers like PGPR (Plant Growth Promoting Rhizobacteria), which include bacteria such as Azotobacter sp., Azospirillum sp., Bacillus sp., Pseudomonas sp., Arthrobacter sp., Bacterium sp., and Mycobacterium sp. PGPR can influence plants directly through nitrogen fixation, phosphate solubilization, growth hormone production, and indirectly by improving growth conditions (Zainudin Abadi and Aini, 2014). PGPR usage among farmers is still rare and primarily used for research, though some PGPR products are commercially available in Indonesia. PGPR generally functions as a growth stimulant, nutrient provider, and pathogen controller.

Planting systems, such as monoculture and intercropping, are vital for increasing production. Monoculture involves planting a single crop on a plot of land, meanwhile, in intercropping, there are at least two types of plants that grow and produce simultaneously on the same land (Hu et al., 2019; Li et al., 2020). In this study, chili peppers are intercropped with papaya (Carica papaya L.) aged 3-4 months. Papaya, widely cultivated in Indonesia, is a perennial plant available year-round (Barus, 2008). The sweet and refreshing taste makes papaya popular among Indonesians. Intercropping aims to optimize production and maintain soil fertility (Prasetyo *et al.*, 2009).

The planting system used by farmers determines the yield. Enhancing crop production involves proper land management to achieve maximum yield while minimizing risks and preventing crop failure. Studies on planting systems and PGPR application in chili peppers are limited, necessitating further research on planting systems, optimal PGPR dosage recommendations, and productivity enhancement.

RESEARCH METHODS

The research was conducted at the Fruit and Vegetable Garden, Kampung Pelangi RW 09, Merjosari Village, Lowokwaru District, Malang City, from September to December 2022. The location has an annual rainfall of 1883 mm, an altitude of 452 meters above sea level, and a maximum temperature of 26º C (Harjanto, 2021). The study used a nested design with two factors: PGPR concentration and planting system. The first factor was planting system application with two levels: T1 (Monoculture) and T2 (Intercropping). The second factor was PGPR concentration application with four levels: P0 (No PGPR), P1 (10 ml/l), P2 (20 ml/l), and P3 (30 ml/l).

Observations included growth and yield parameters. Data were analyzed using analysis of variance (ANOVA) at a 5% level to determine the significant effect of treatments. Significant results were further tested using the least significant difference (LSD) test at a 5% level.

RESULTS AND DISCUSSION

Tables 1 to 3 show increased plant height, leaf number, and leaf area with increasing PGPR concentration. Monoculture systems produced better results compared to intercropping.

Table 1. Plant height of chili pepper with planting system and PGPR treatment from 10 to 40 days after planting (DAP)

Plant height (cm)					
Treatment		10 DAP	20 DAP	30 DAP	40 DAP
	PGPR				
Intercropping	0 ml	13.48 a	15.10 a	17.32 a	18.05 a
	10 ml	14.33 a	16.40 b	18.71 a	20.02 b
	20 ml	15.75 b	17.35 bc	20.59 b	23.39 c
	30 ml	16.42 b	17.58 c	22.18 c	30.38 d
Monoculture	0 ml	16.45 b	18.77 d	23.21 d	31.6 d
	10 ml	17.39 c	19.66 e	26.01 e	35.62 e
	20 ml	17.90 c	21.10 f	28.83 f	39.31 f
	30 ml	19.93 d	22.45 g	33.97 g	42.20 g
LSD 5%		0.85	0.99	1.43	1.79
CV (%)		7.14	7.36	8.25	8.12

Explanation: Numbers followed by the same letter at the same observation age are not significantly different based on the 5% LSD test; DAP = Days After Planting; LSD = Least Significant Difference; CV = Coefficient of Variation.

Table 2. Number of leaves of chili pepper with planting system and PGPR treatment from 10 to 40 DAP

Number of leaves					
Treatment		10 DAP	20 DAP	30 DAP	40 DAP
	PGPR				
Intercropping	0 ml	6.00 a	7.05 a	10.55 a	14.55 a
	10 ml	6.58 a	8.02 b	12.73 b	16.16 a
	20 ml	7.09 b	8.79 c	13.60 c	18.51 b
	30 ml	7.49 bc	9.00 c	16.47 d	24.55 c
Monoculture	0 ml	7.68 c	11.37 d	17.46 e	26.65 d
	10 ml	8.15 de	12.99 e	21.62 f	37.70 e
	20 ml	8.58 e	15.41 f	28.29 g	43.11 f
	30 ml	10.12 f	17.12 g	34.14 h	46.45 g
LSD 5%		0.70	0.58	1.89	2.27
CV (%)		12.48	7.18	13.37	10.96

Explanation: Numbers followed by the same letter at the same observation age are not significantly different based on the 5% LSD test; DAP = Days After Planting; LSD = Least Significant Difference; CV = Coefficient of Variation.

Table 3. Leaf area of chili pepper with planting system and PGPR treatment from 10 to 40 DAP

Leaf area (cm^2 $plant^{-1}$)					
Treatment		10 DAP	20 DAP	30 DAP	40 DAP
	PGPR				
Intercropping	0 ml	51.08 a	71.82 a	151.11 a	171.55 a
	10 ml	55.34 b	80.84 b	158.75 a	188.04 a
	20 ml	59.92 c	91.83 c	171.17 b	201.42 b
	30 ml	62.75 d	100.54 d	176.30 bc	220.22 c
Monoculture	0 ml	63.84 d	103.53 d	180.3 c	225.49 c
	10 ml	67.05 e	119.88 e	191.51 d	240.58 d
	20 ml	70.45 f	129.95 f	221.24 e	250.94 f
	30 ml	74.02 g	158.73 g	231.02 f	301.33 g
LSD 5%		4.28	14.22	12.20	19.78
CV (%)		9.30	18.19	9.77	12.01

Explanation: Numbers followed by the same letter at the same observation age are not significantly different based on the 5% LSD test; DAP = Days After Planting; LSD = Least Significant Difference; CV = Coefficient of Variation.

The lowest crop growth rate was observed in intercropping with 0 ml/l PGPR, while the highest growth rate was observed in monoculture with 30 ml/l PGPR (Table 4).

Table 4. Crop growth rate of chili pepper with planting system and PGPR treatment from 10 to 40 DAP

Crop growth rate ($g/cm^2/day$)				
Treatment		10-20 DAP	20-30 DAP	30-40 DAP
	PGPR			
Intercropping	0 ml	0.017 a	0.011 a	0.017 a
	10 ml	0.010 b	0.016 b	0.017 a
	20 ml	0.012 c	0.017 b	0.020 b
	30 ml	0.015 d	0.018 c	0.025 c
Monoculture	0 ml	0.017 d	0.019 cd	0.029 d
	10 ml	0.019 e	0.024 d	0.033 e
	20 ml	0.022 f	0.026 e	0.039 f
	30 ml	0.024 g	0.035 f	0.060 g
LSD 5%		0.001	0.001	0.02
CV (%)		9.92	11.55	12.52

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Explanation: Numbers followed by the same letter at the same observation age are not significantly different based on the 5% LSD test; DAP = Days After Planting; LSD = Least Significant Difference; CV = Coefficient of Variation.

Based on the observations, Table 5 shows that there is an increase in the number of fruits per plant as the concentration of PGPR applied increases. The same trend can be seen in the planting system, where chili plants grown in a monoculture system produced more fruits compared to chili plants grown in an intercropping system. The lowest average fruit weight per plant obtained in this study (Table 5) was 49.67 g in the intercropping system with 0 ml/l PGPR concentration, while the highest fruit weight was 100.34 g in the monoculture system with 30 ml/l PGPR concentration.

In the intercropping system, increasing the PGPR concentration from 0 ml/l to 10 ml/l resulted in a 15.75% increase in yield, from 0 ml/l to 20 ml/l resulted in a 32.96% increase, and from 0 ml/l to 30 ml/l resulted in a 56.04% increase.

In the monoculture system, increasing the PGPR concentration from 0 ml/l to 10 ml/l resulted in a 10.36% increase in yield, from 0 ml/l to 20 ml/l resulted in a 16.58% increase, and from 0 ml/l to 30 ml/l resulted in a 26.95% increase. The lowest average fruit weight per hectare obtained in this study was 2.73 tons/ha in the intercropping system with 0 ml/l PGPR concentration, while the highest fruit weight per hectare was 5.51 tons/ha in the monoculture system with 30 ml/l PGPR concentration.

Tabel 4. Number of fruits, fruit weight, and yield with planting system and PGPR treatment

Treatment	Number of fruits **(fruit plant^{-1})**			
	PGPR (ml)			
	0	**10**	**20**	**30**
Intercropping	28.20 a	34.28 b	38.15 c	41.89 d
Monoculture	44.37 d	49.82 e	58.17 f	61.65 g
LSD 5%	3.42			
CV (%)	10.53			
Treatment	Fruit weight **(g plant^{-1})**			
	PGPR (ml)			
	0	**10**	**20**	**30**
Intercropping	49.67 a	57.56 b	66.11 c	75.83 d
Monoculture	80.78 d	87.20 e	92.08 f	100.34 g
LSD 5%	6.73			
CV (%)	12.11			
Treatment	**Yield (ton ha^{-1})**			
	PGPR (ml)			
	0	**10**	**20**	**30**
Intercropping	2.73 a	3.16 b	3.63 c	4.26 d

Monoculture	4.34 d	4.79 e	5.06 f	5.51 g
LSD 5%		0.36		
CV (%)		11.78		

Explanation: Numbers followed by the same letter at the same columns and rows age are not significantly different based on the 5% LSD test; DAP = Days After Planting; LSD = Least Significant Difference; CV = Coefficient of Variation.

Based on the results, there was a significant interaction between planting systems and PGPR on observed plant height, number of leaves, leaf area, flowering age, total dry weight, growth rate, number of fruits per plant, fruit weight, and yield. Each treatment influenced the outcomes, with higher PGPR concentrations leading to increased growth and yield. Monoculture planting also produced higher results compared to intercropping with papaya plants aged 3-4 months. The differences were due to variations in growth environment factors such as light, air, and nutrient absorption. Monoculture plants received more sunlight, necessary for photosynthesis, benefiting both the plants and PGPR bacteria.

According to Ajis and Wahyu (2020), chili peppers grow well with a minimum sunlight intensity of 4287 lux compared to lower intensity. Lux meter measurements showed 3630 lux for intercropped chili peppers shaded by papaya leaves and 8010 lux for monoculture chili peppers with no shading. Increased sunlight exposure resulted in higher plant yields due to less competition for nutrients, water, and space (Kim et al., 2019). This reflects the results of Permanasari and Kastono (2012) on corn and soybeans, where monoculture yielded higher results than intercropping. According to Zainudin et al. (2014), PGPR can enhance plant growth even under saline stress. PGPR inoculation increased chili pepper plant height, stimulating growth by producing IAA, which promotes cell elongation and nutrient absorption (Fitria et al., 2009).

The higher the PGPR concentration, the higher the plant height. This is consistent with Marom et al. (2017) on the effectiveness of PGPR application timing and concentration on peanut production, where higher PGPR concentrations yielded higher results. Similarly, Iswati (2012) found that higher PGPR concentrations correlated with plant growth.

Monoculture planting also resulted in a higher number of leaves due to better sunlight exposure, necessary for photosynthesis. Leaves are primary photosynthetic organs, and increased photosynthesis capability leads to more leaves (Yuliasmara, 2012). In an intercropping system, light intensity affects the growth and development of each plant. For example, in basil plants, the highest yields are obtained in plants that receive high light intensity or no shade (Castronuovo et al., 2019). PGPR and monoculture interactions increased leaf number, as PGPR bacteria produced phytohormones that induced plant growth. Khalimi and Wirya (2009) stated that PGPR usage increased the maximum number of leaves in plants.

The results showed that monoculture planting resulted in larger leaf area, consistent with Lal et al. (2019), who found that monoculture produced higher leaf areas in mustard greens compared to intercropping. Monoculture plants received more sunlight, essential for photosynthesis, leading to increased leaf area. PGPR application also affected leaf area, as higher PGPR concentrations improved plant growth. According to Naikofi and Rusae (2017), PGPR is a consortium of bacteria that colonize plant roots, improving growth, yield, and soil fertility.

PGPR influenced flowering age, with the smallest flowering age in intercropping with 0 ml/l PGPR (58.83 DAP) and the largest in monoculture with 30 ml/l PGPR (42.58 DAP). Flowering age differences were due to factors like shading, nutrient competition, and microclimate variations (Pimental et al., 1999). According to Maheshwari (2011), Azotobacter, Azospirillum, Rhizobium, Bacillus, and Pseudomonas are genera included in PGPR and play a role in increasing nutrient absorption by plants. In addition, PGPR improves plant health through various mechanisms such as ethylene reduction, phytohormone production, exopolysaccharide production, systemic resistance induction, phosphorus solubilization, nitrogen fixation, and siderophore production (Maheshwari, 2011; Nadeem et al., 2014: Hariyono et al., 2021). Rohmawati et al. (2017) found that PGPR application accelerated flowering in eggplants with increasing PGPR concentrations.

The results showed that monoculture planting and PGPR application significantly affected total fresh and dry weight. Monoculture produced higher weights due to better sunlight exposure and less competition for nutrients. Increased photosynthesis led to more organic compounds translocated throughout the plant, increasing dry weight (Nurdin, 2011). Monoculture planting also provided better sunlight exposure, essential for photosynthesis, compared to intercropping where shading by papaya plants reduced sunlight exposure. PGPR application improved plant growth by enhancing nutrient availability and promoting growth-promoting bacteria. Raka et al. (2012) stated that PGPR application increased plant growth parameters like maximum plant height and fresh weight.

PGPR application also affected plant growth rate. Monoculture plants received more sunlight, essential for photosynthesis and growth. Reduced nutrient competition in monoculture accelerated growth, increasing dry weight and growth rate (Awad *et al*., 2001). PGPR provided nutrients like phosphorus, enhancing plant growth (Swain and Ray, 2009). ANOVA tests showed significant effects of planting systems and PGPR on fruit number, fruit weight, and yield. Monoculture produced higher fruit weight due to better photosynthesis and less competition for nutrients. Higher PGPR concentrations improved fruit weight and yield. PGPR bacteria facilitated nutrient absorption, enhancing plant growth and fruit production (Ningrum et al., 2017). Higher asimilat production from photosynthesis increased fruit weight. Monoculture planting and PGPR application significantly influenced fruit yield, with monoculture producing higher yields due to better sunlight exposure (Jeeatid et al., 2018; Kim et al., 2019). A'yun et al. (2013) found that PGPR application increased chili pepper fruit weight. PGPR-produced IAA hormone is crucial for growth, enhancing yield and quality, stimulating cell development, root formation, flowering, growth, and enzyme activity. This study showed that monoculture planting with increasing PGPR concentrations produced higher fruit weight compared to intercropping at each PGPR concentration.

CONCLUSION

Based on the research conducted, the following conclusions can be drawn:

1. The best planting system used in this research is the monoculture system because it provides better growth and yield for chili pepper plants

compared to the intercropping system, where chili peppers are intercropped with 3-4 months old papaya plants.

2. The best PGPR concentration used in this research is 30 ml/l, as the growth and yield of the plants increase with higher PGPR concentrations.
3. Chili pepper plants can be intercropped, but the yield decreases. Intercropped chili peppers with a 30 ml/l PGPR concentration prod yields similar to monoculture chili peppers with 0 ml/l PG concentration or control.

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