Application of Plant Growth Promoting Rhizobacteria on Vegetative Growth in Chili Plants (*Capsicum frutescens* L.)

Wahyu Astiko* and Meriyati
Agroecotechnology Study Program, Faculty of Agriculture, Mataram University, Indonesia

Abstract:- Cayenne pepper is a significant plant in tropical regions, utilized not only as a culinary spice but also in the pharmaceutical industry. An effective strategy for enhancing the physical, chemical, and biological quality of soil is the employment of plant growth-promoting rhizobacteria (PGPR). PGPR, a soil microorganism that colonizes plant roots, can accelerate growth and protect against certain pathogens. The use of PGPR, particularly in biocontrol of plant pathogens and biofertilization, is prevalent across various global regions. This study evaluates the effectiveness of PGPR in boosting the growth of cayenne pepper and was conducted in Peresak Village, Narmada District, West Lombok Regency, NTB Province. The methodology implemented was a Completely Randomized Design (CRD) experiment with five treatments and five replications, totaling 25 plant units. The treatments included a control (P0 ml/L) and four PGPR concentrations: P1 (10 ml/L), P2 (20 ml/L), P3 (30 ml/L), and P4 (40 ml/L). Each PGPR dose was dissolved in 1 liter of water and administered at 200 ml per polybag. The findings indicated that PGPR application significantly impacted the growth of cayenne pepper plants, notably increasing plant height, leaf count, branch count, and flower count. The 30 ml/L PGPR concentration (P3) proved most effective in enhancing these growth parameters. The results underscore the substantial benefits of incorporating PGPR as a biofertilizer agent in agricultural practices to optimize crop yields.

***Keywords**:- Biofertilization, Cayenne Pepper, Plant Growth Promoting Rhizobacteria, Plant Growth*

I. INTRODUCTION

Chili pepper (*Capsicum frutescens* L.), belonging to the Solanaceae family, is a crucial plant in tropical regions. It serves dual purposes: as a vital spice in Indonesian culinary practices and as a raw material in the pharmaceutical industry [1]. Owing to its staple presence in daily diets, cayenne pepper is consumed by nearly the entire Indonesian population, with an average annual consumption of 4 kg per person [2].

Cayenne pepper is nutrient-rich, containing calories, carbohydrates, proteins, fats, and a variety of essential minerals and vitamins [3]. Additionally, it contains medicinal compounds such as oleoresin, capsaicin, and bioflavonoids, which are known to provide health benefits including alleviating sinusitis and migraine symptoms, as well as fortifying weak limbs [4].

To enhance growth quality and disease resistance in plants, one effective approach is the application of plant growth-promoting rhizobacteria (PGPR) [5]. PGPR are soil microbes that colonize plant roots, aiding in growth enhancement and pathogen protection [6]. This method is widely adopted globally and integrates pest management and biofertilization strategies to boost crop yields and improve soil fertility [7].

This study aims to assess the impact of application PGPR dosages on the vegetative growth of cayenne pepper within a rhizosphere rich in organic energy sources derived from root exudates, which also fosters the proliferation of various microbial types.

II. MATERIALS AND METHODS

A. Time and Place

The research was conducted over a two-month period from February 21 to April 22, 2023, in Peresak Village, Narmada District, West Lombok Regency, West Nusa Tenggara Province.

B. Research Materials and Tools

The tools utilized in this study included shovels, hoes, sprayers, buckets, 220 ml plastic cups, rulers, measuring cups, stationery items, stirrers, and cameras. The materials used comprised cayenne pepper seeds, polybags, soil, compost, raw husks, *Beauveria bassiana*, vegetable pesticides, and water.

C. Implementation Method

The research was conducted in the Green House at the Agricultural Plant Protection Center (BPTP), using polybags and an experimental design with five treatments, each replicated five times, resulting in a total of 25 observed plants. The treatments included: control (P0, no PGPR application), P1 (10 ml/L), P2 (20 ml/L), P3 (30 ml/L), and P4 (40 ml/L). Observed parameters included

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24MAY793

plant height, number of leaves, number of branches, and flowering age of the cayenne pepper plants.

D. Implementation Stages

Eighteen-day-old chili seedlings, uniform in height and leaf number, were prepared and transferred to the Green House, labeled, and randomized. The initial PGPR application was conducted three days later, at 21 days after planting (DAP). Subsequent PGPR applications were made weekly at 28 DAP and 35 DAP. Weekly observations of chili growth were performed.

E. Maintenance Stages

Watering was performed twice daily, in the morning and evening, based on soil conditions to meet the plants' water requirements. Over-watering was avoided to prevent root damage, including rot. Replanting of dead or diseased plants was carried out with pre-prepared seeds. Weed removal was conducted mechanically as needed, particularly when weeds significantly encroached on the plants or polybags. Pruning of lateral shoots below branches was done once at 35 DAP or when the plants reached 16-23 cm in height to promote vegetative growth. Pest control was achieved through mechanical means and the application of *Beauveria bassiana* and botanical pesticides to all plant parts to manage aphid infestations.

F. Parameter Observation

Plant height was measured weekly from the stem base above the ground to the tip of the growing point using a ruler. The initial measurement was taken before the first PGPR application at 21 DAP to establish baseline heights for each treatment. Subsequent measurements were made at 28, 35, and 42 DAP. Leaf count was recorded weekly, concurrent with plant height measurements. The number of productive branches, indicated by the presence of flowers, and flower counts were assessed at 42 DAP. Observations included counting the branches that bore flowers and the number of flowers, focusing on unopened petals and wide, star-like flower stalks.

III. RESULTS AND DISCUSSION

A. Chili Plant Height

Observational data revealed that the application of PGPR significantly influenced the height growth of chili plants at 28, 35, and 42 days after planting (DAP), as depicted in Figure 1.

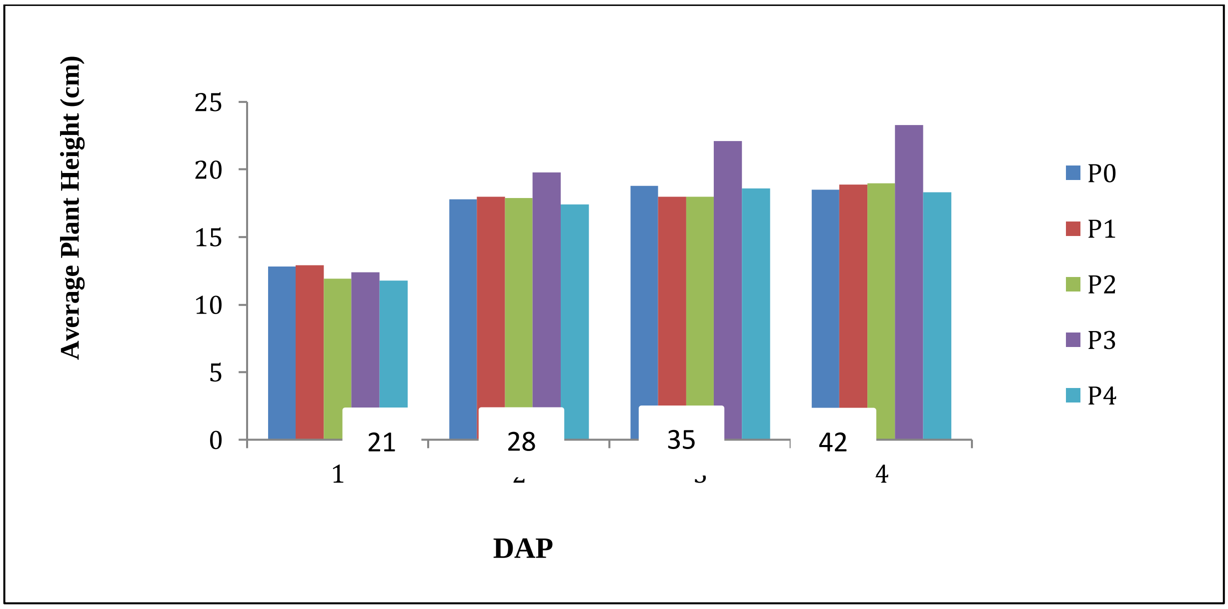

Fig 1. Graph Depicting the Average Height of Cayenne Pepper Plants at 21, 28, 35, and 42 DAP for each Treatment

Figure 1 demonstrates that each PGPR dose positively affected plant height, particularly in comparison to the control group which received no PGPR. Notably, the treatment with 30 ml/L of water resulted in the highest growth, achieving average plant heights of 19.8 cm, 22.1 cm, and 23.3 cm at successive observations. Plant height is a critical measure of both growth rate and the effectiveness of environmental treatments. PGPR likely enhances plant height through the production of phytohormones, which improve root surface area and nutrient availability.

The most significant height at 28 DAP was observed in the P3 treatment (30 ml/L) at 19.8 cm, while the P4 treatment (40 ml/L) recorded the lowest at 17.4 cm. By 35 DAP, the highest plant height remained with P3 at 22.1 cm. The lowest heights were noted in P1 (10 ml/L) and P2 (20 ml/L) treatments, both measuring 18 cm, with P0 (control) at 18.8 cm and P4 at 18.6 cm. At 42 DAP, P3 continued to exhibit the best growth at 23.3 cm, while P4 recorded the lowest at 18.3 cm.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24MAY793

The optimal growth consistently observed in the P3 treatment (30 ml/L) suggests that this PGPR concentration effectively stimulates growth hormone activity, particularly auxins, which contribute to cell enlargement and stem elongation. Conversely, the P4 treatment (40 ml/L) consistently showed the lowest growth rates, indicating possible inhibitory or toxic effects at higher PGPR concentrations [8].

Meanwhile, the P4 treatment (40 ml/L) consistently resulted in the lowest growth across all observation periods. This suggests that PGPR concentrations above 30 ml/L might have inhibitory or even toxic effects on plants. As previously noted, excessive doses of PGPR can induce physiological stress in plants [9].

The control treatment and lower PGPR doses (P1 = 10 ml/L and P2 = 20 ml/L) yielded lower results than the P3 treatment (30 ml/L) but were more effective than the P4 treatment (40 ml/L). This supports the hypothesis that PGPR indeed plays a role in plant growth; however, its effectiveness heavily depends on the administered dose. Insufficient PGPR dosages may not adequately stimulate a significant biological response in plants [10].

This observation underscores the importance of dose adjustment in PGPR applications to optimize plant growth while also considering the potential negative effects of excessive doses [11]. Additionally, this study highlights the need for further investigation into the interactions between PGPR and chili plants, particularly regarding their impact on various growth parameters [12].

The graph demonstrates that PGPR significantly enhances plant growth compared to the control group, which did not receive PGPR. Plant height is commonly used as a growth indicator and a parameter for assessing the effectiveness of treatments. PGPR promotes the production of phytohormones, such as auxin and cytokinin, which are crucial for root development and cell division, respectively [13]. Additionally, the bacteria in PGPR act as growth stimulants, enhancing the plant's ability to absorb nutrients, particularly phosphorus, during the vegetative phase—this is essential for plant energy metabolism [14].

PGPR not only enhances plant growth but also assists plants in coping with abiotic stress, thereby playing a crucial role in plant survival [15]. However, the effectiveness of PGPR can vary depending on environmental conditions and the specific strains of bacteria used. This variability underscores the importance of selecting appropriate strains and managing the soil microbiome effectively [16].

B. Number of Chili Plant Leaves

Observational results indicate that the application of PGPR significantly influenced the number of leaves on chili plants, particularly at 28, 35, and 42 days after planting (DAP). The average number of leaves per plant is presented in Figure 2.

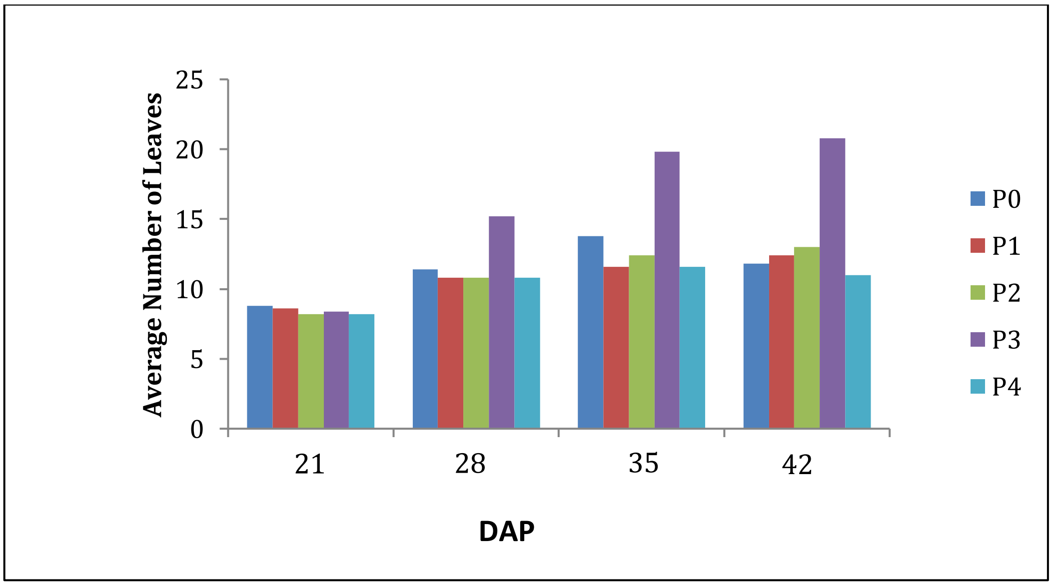

Fig 2. Graph Showing the Average Number of Leaves on Cayenne Pepper Plants at 21, 28, 35, and 42 DAP for each Treatment.

Figure 2 shows that various doses of PGPR significantly affect the growth of chili plant leaves compared to control groups that did not receive PGPR. Notably, the treatment with 30 ml/L of water produced the best results; the average number of leaves at each observation point was 15.2, 19.8, and 20.8 leaves, respectively.

Observational results indicated that PGPR treatment influenced the leaf count of chili plants. At 28 days after planting (DAP), the P3 treatment (30 ml/L) yielded the highest number of leaves, with an average of 15.2. Conversely, treatments P1 (10 ml/L), P2 (20 ml/L), and P4 (40 ml/L) resulted in the lowest leaf counts, each averaging 10.8 leaves. Meanwhile, the control group (P0) recorded an average of 11.4 leaves.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24MAY793

At 35 days after planting (DAP), the P3 treatment (30 ml/L) continued to produce the highest number of leaves, with an average of 19.8 leaves. The treatments P4 (40 ml/L) and P1 (10 ml/L) yielded the lowest number of leaves, each with an average of 11.6 leaves. Meanwhile, the control group recorded an average of 13.8 leaves.

Observations at 42 days after planting (DAP) revealed similar trends. The P3 treatment (30 ml/L) continued to show the best results, producing 20.8 leaves. The P4 treatment (40 ml/L) resulted in the lowest yield with 11 leaves. Meanwhile, the control group had 11.8 leaves, and treatments P1 (10 ml/L) and P2 (20 ml/L) recorded 12.4 leaves and 13 leaves, respectively.

Observations indicated that the P3 treatment (30 ml/L PGPR) consistently produced the best results in increasing the number of leaves on chili plants at various growth stages (28, 35, and 42 days after transplanting). This consistent response underscores the significant role of PGPR in facilitating physiological improvements in plants. PGPR is known to secrete phytohormones such as auxin and cytokinin, which are crucial for cell division, elongation, and tissue differentiation, thereby promoting the formation of new leaves [17].

Treatments with higher (P4 = 40 ml/L) and lower (P1 = 10 ml/L and P2 = 20 ml/L) PGPR doses were less effective compared to the P3 treatment (30 ml/L). This suggests that there is an optimal PGPR concentration that supports plant growth, beyond which the beneficial effects diminish or even turn adverse. The detrimental effects at higher concentrations may be due to an increased bioburden or unfavorable microbial competition, which could undermine the advantages of PGPR bioaugmentation [18].

PGPR treatments resulted in an increased number of leaves, confirming the effectiveness of PGPR as a bio-stimulator [19]. Additionally, other research indicates that PGPR can enhance nutrient utilization efficiency, particularly of nitrogen and phosphorus, which are essential for supporting leaf formation and growth [20].

The observational results demonstrate that the application of PGPR significantly affects the growth of chili plants, particularly in terms of plant height and leaf count. The treatment using a PGPR concentration of 30 ml/L yielded the best results for these two parameters at 28, 35, and 42 days after planting (DAP), compared to the control group which did not receive PGPR treatment. However, the growth increments in plant height and leaf number were not significant at 35 and 42 DAP due to pest attacks. While PGPR is generally known to enhance plant growth and yield by stimulating growth and optimizing nitrogen absorption during the vegetative phase, the observations at 35 DAP showed suboptimal growth. This was primarily due to aphid attacks, which were initially observed at 30 DAP as silver-brown spots on young shoots and leaves. The infestation worsened by 35 DAP, with aphids forming colonies on the underside of leaves, marked by the emergence of blackish-green eggs, indicating the beginning of their reproductive phase.


Fig 3. Aphid Attacks on the Leaves and Shoots of Chili Plants

Given the ongoing aphid attacks, botanical pesticides were applied to the affected plants. Observations conducted at 40 days after planting (DAP) indicated a decrease in aphid activity. The upper parts of the chili plants began showing signs of recovery, and flower formation commenced. However, due to the impact of earlier aphid attacks, the production of chili flowers was not optimal.

C. Number of Chili Plant Branches

Observations on the number of branches were conducted at the end of the vegetative phase, specifically at 42 days after planting (DAP). The results indicate that the application of PGPR significantly increases the number of branches on chili plants. The average number of branches is presented in Figure 4.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24MAY793

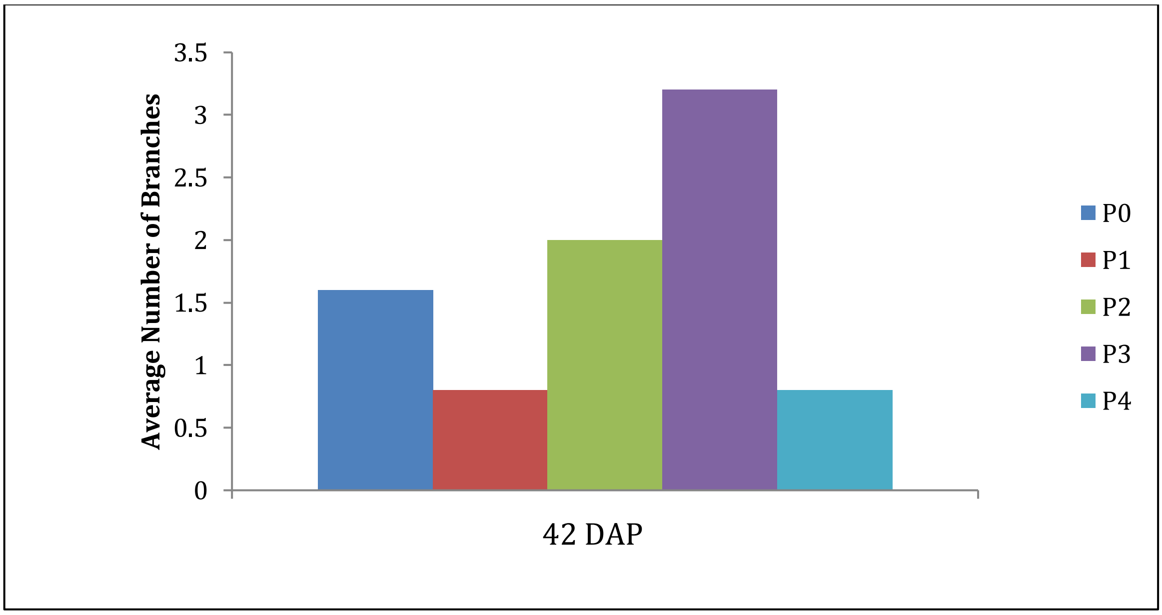

Fig 4. Graph Showing the Average Number of Cayenne Pepper Branches for each Treatment at 42 DAP

Figure 4 demonstrates that various doses of PGPR significantly influenced the growth of chili plant branches, especially when compared to the control group that did not receive PGPR treatment. Notably, the treatment with 30 ml/L of water produced the most favorable results, yielding the highest average number of branches, with 3.2 branches per plant at 42 days after planting (DAP).

Observational results indicate that the application of PGPR significantly influences the number of branches on chili plants. After averaging the data, the highest number of branches was observed in the P3 treatment (30 ml/L), with an average of 3.2 branches per plant at 42 days after planting (DAP). The control group (P0) had an average of 1.6 branches, while treatments P1 (10 ml/L) and P4 (40 ml/L) each produced an average of 0.8 branches.

The observation results demonstrate that PGPR application significantly impacts the number of branches on chili plants. The P3 treatment (30 ml/L) exhibited the most substantial increase, with an average of 3.2 branches per plant at 42 days after planting (DAP), while the control and other treatments showed lower yields. The addition of PGPR appears to enhance biological activity in the rhizosphere, which aids in increasing branch formation by improving the nutritional and hormonal status of the plant [21].

PGPR enhances the production of phytohormones such as auxin, which plays a direct role in promoting cell division and the formation of new branches [22]. This positive effect was especially noticeable at optimal PGPR concentrations, as evidenced by the P3 treatment. This treatment achieved an ideal balance between nutritional application and hormonal stimulation, avoiding the toxicity observed at higher concentrations, such as in treatment P4.

Observations also indicated that low doses of PGPR (as in P1) and the control group without PGPR (P0) resulted in fewer branches. This can be attributed to insufficient levels of phytohormones necessary for supporting plant branch formation. Lower doses may not adequately stimulate a significant biological response in the plants [23].

However, the effectiveness of PGPR treatment can vary depending on environmental conditions and the specific characteristics of the plants being grown. This highlights the importance of tailoring PGPR doses to the unique requirements of each agricultural context [24].

D. Number of Chili Plant Flowers

Observing the number of flowers on chili plants involves noting signs of flowering, such as the appearance of slightly bloated flower petals that have not yet fully opened. These observations were conducted when the plants were 42 days after planting (DAP). The observations revealed that the flower petals expanded, taking on a star-like shape, which marks the onset of flowering.

Based on these observations, it is evident that the application of PGPR significantly affects the number of flowers on chili plants. The average number of flowers from various PGPR treatments is displayed in Figure 5. This graph illustrates the average number of cayenne pepper flowers per treatment at 42 days after planting (DAP).

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24MAY793

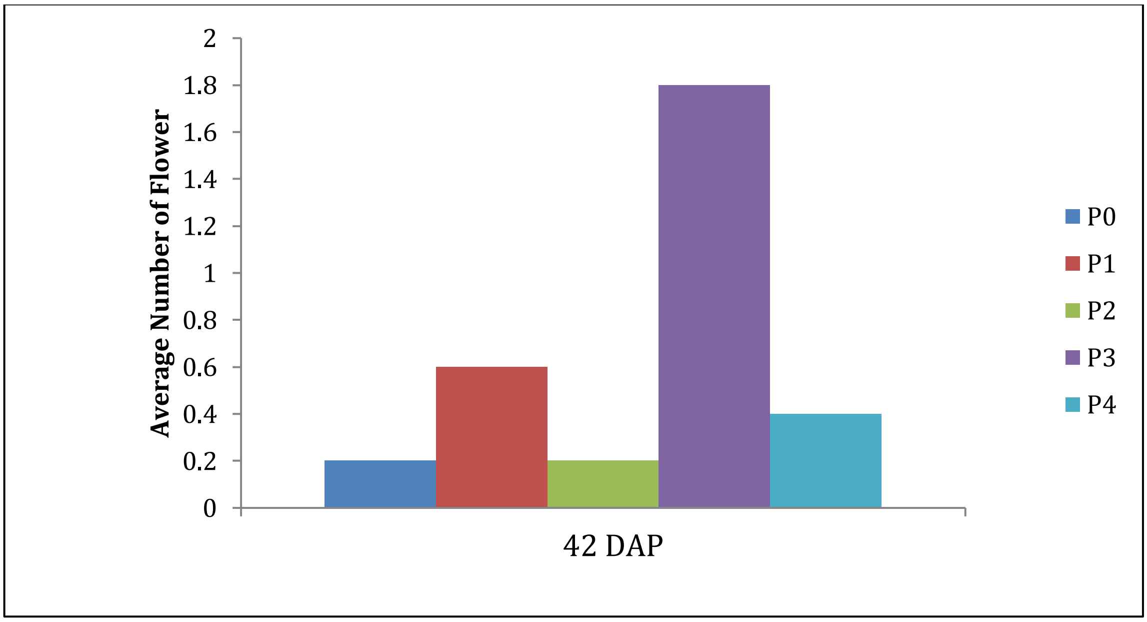

Fig 5. Graph Showing the Average Number of Cayenne Pepper Flowers for each Treatment at 42 DAP.

Data analysis indicated that each dose of PGPR had an impact on increasing the number of flowers compared to the control group, which did not receive PGPR. The treatment with a concentration of 30 ml/L of water yielded the highest results, with an average number of flowers measuring 1.8 cm in diameter. Meanwhile, other treatments varied in outcomes; the 10 ml/L treatment resulted in flowers measuring 0.6 cm, the 40 ml/L treatment produced flowers measuring 0.4 cm, and both the control and the 20 ml/L treatments resulted in flowers averaging 0.2 cm in diameter.

The application of PGPR at a concentration of 30 ml/L of water resulted in the highest number of flowers, with an average size reaching 1.8 cm. This demonstrates the effectiveness of PGPR in enhancing the plant's capacity to produce more flowers. The addition of PGPR likely improves the nutritional or hormonal balance of the plants, which in turn promotes more vigorous flowering.

Other treatments yielded mixed results; the 10 ml/L treatment produced flowers with an average size of 0.6 cm, and the 40 ml/L treatment yielded flowers averaging 0.4 cm, demonstrating that PGPR concentrations either lower or higher than 30 ml/L were not as effective as the optimal concentration. Meanwhile, the control and the 20 ml/L treatment both resulted in the smallest flowers, measuring only 0.2 cm on average. This suggests that without PGPR intervention or with suboptimal doses, plants do not significantly increase the number of flowers.

These results align with research indicating that PGPR can enhance plant growth and productivity through various mechanisms, including increased nutrient absorption, improved soil physical properties, and regulation of plant hormones [25]; [26]. Specifically, Bacillus spp., commonly used as PGPR, are known to promote root growth and flowering by producing phytohormones such as auxin and cytokinin [27].

IV. CONCLUSION

The findings of this research demonstrate that PGPR, a beneficial microorganism found around plant roots, can significantly enhance growth and provide protection against certain pathogens. Observational results indicate that the application of PGPR markedly affects the growth of chili plants, including increases in plant height, leaf count, branch number, and flower production. The treatment with a PGPR concentration of 30 ml/L (P3) in water was found to be the most effective in improving these four aspects. This suggests that using PGPR is substantially more beneficial for supporting the vegetative growth of chili plants compared to those that did not receive any PGPR treatment (control). These conclusions underscore the importance of PGPR as a biofertilizer agent that can be integrated into agricultural practices to optimize crop yields.

ACKNOWLEDGMENT

The author would like to express gratitude to the Faculty of Agriculture at the University of Mataram for providing the research funding grant.

REFERENCES

[1]. Duranova, H., Valkova, V., & Gabriny, L. 2022. Chili peppers (Capsicum spp.): The spice not only for cuisine purposes: An update on current knowledge. *Phytochemistry Reviews*, *21*(4), 1379-1413.
[2]. Ministry of Agriculture, 2016. *Cayenne Papper Production by Province, 2011-2016.* http://www.pertanian.go.id/e-mail/indexsearch.php. Diakses pada 25 Juli 2022
[3]. Olatunji, T. L., & Afolayan, A. J. 2018. The suitability of chili pepper (Capsicum annuum L.) for alleviating human micronutrient dietary deficiencies: A review. *Food science & nutrition*, *6*(8), 2239-2251.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24MAY793

[4]. Saleh, B. K., Omer, A., & Teweldemedhin, B. J. M. F. P. T. 2018. Medicinal uses and health benefits of chili pepper (*Capsicum* spp.): a review. *MOJ Food Process Technol*, *6*(4), 325-328.
[5]. Meena, M., Swapnil, P., Divyanshu, K., Kumar, S., Harish, Tripathi, Y. N., & Upadhyay, R. S. 2020. PGPR-mediated induction of systemic resistance and physiochemical alterations in plants against the pathogens: Current perspectives. *Journal of Basic Microbiology*, *60*(10), 828-861.
[6]. Hayat, R., Ali, S., Amara, U., Khalid, R., & Ahmed, I. 2010. Soil beneficial bacteria and their role in plant growth promotion: a review. *Annals of microbiology*, *60*, 579-598.
[7]. Basu, A., Prasad, P., Das, S. N., Kalam, S., Sayyed, R. Z., Reddy, M. S., & El Enshasy, H. 2021. Plant growth promoting rhizobacteria (PGPR) as green bioinoculants: recent developments, constraints, and prospects. *Sustainability*, *13*(3), 1140.
[8]. Tsukanova, K. A., Meyer, J. J. M., & Bibikova, T. N. 2017. Effect of plant growth-promoting Rhizobacteria on plant hormone homeostasis. *South African journal of botany*, *113*, 91-102.
[9]. Etesami, H., & Maheshwari, D. K. 2018. Use of plant growth promoting rhizobacteria (PGPRs) with multiple plant growth promoting traits in stress agriculture: Action mechanisms and future prospects. *Ecotoxicology and environmental safety*, *156*, 225-246.
[10]. Prasad, M., Srinivasan, R., Chaudhary, M., Choudhary, M., & Jat, L. K. 2019. Plant growth promoting rhizobacteria (PGPR) for sustainable agriculture: perspectives and challenges. *PGPR amelioration in sustainable agriculture*, 129-157.
[11]. Banerjee, M. R., Yesmin, L., Vessey, J. K., & Rai, M. 2006. Plant-growth-promoting rhizobacteria as biofertilizers and biopesticides. *Handbook of microbial biofertilizers. Food Products Press, New York*, 137-181.
[12]. Grover, M., Bodhankar, S., Sharma, A., Sharma, P., Singh, J., & Nain, L. 2021. PGPR mediated alterations in root traits: way toward sustainable crop production. *Frontiers in Sustainable Food Systems*, *4*, 618230.
[13]. Vacheron, J., Desbrosses, G., Bouffaud, M. L., Touraine, B., Moënne-Loccoz, Y., Muller, D., & Prigent-Combaret, C. 2013. Plant growth-promoting rhizobacteria and root system functioning. *Frontiers in plant science*, *4*, 57135.
[14]. Gupta, G., Parihar, S. S., Ahirwar, N. K., Snehi, S. K., & Singh, V. 2015. Plant growth promoting rhizobacteria (PGPR): current and future prospects for development of sustainable agriculture. *J Microb Biochem Technol*, *7*(2), 096-102.
[15]. Vejan, P., Abdullah, R., Khadiran, T., Ismail, S., & Nasrulhaq Boyce, A. 2016. Role of plant growth promoting rhizobacteria in agricultural sustainability—a review. *Molecules*, *21*(5), 573.
[16]. Vocciante, M., Grifoni, M., Fusini, D., Petruzzelli, G., & Franchi, E. 2022. The role of plant growth-promoting rhizobacteria (PGPR) in mitigating plant's environmental stresses. *Applied sciences*, *12*(3), 1231.
[17]. Maheshwari, D. K., Dheeman, S., & Agarwal, M. 2015. Phytohormone-producing PGPR for sustainable agriculture. *Bacterial metabolites in sustainable agroecosystem*, 159-182.
[18]. Nonthakaew, N., Panbangred, W., Songnuan, W., & Intra, B. 2022. Plant growth-promoting properties of Streptomyces spp. isolates and their impact on mung bean plantlets' rhizosphere microbiome. *Frontiers in microbiology*, *13*, 967415.
[19]. Etesami, H., & Adl, S. M. 2020. Plant growth-promoting rhizobacteria (PGPR) and their action mechanisms in availability of nutrients to plants. *Phyto-Microbiome in stress regulation*, 147-203.
[20]. Mohanty, P., Singh, P. K., Chakraborty, D., Mishra, S., & Pattnaik, R. 2021. Insight into the role of PGPR in sustainable agriculture and environment. *Frontiers in Sustainable Food Systems*, *5*, 667150.
[21]. Saharan, B. S., & Nehra, V. 2011. Plant growth promoting rhizobacteria: a critical review. *Life Sci Med Res*, *21*(1), 30.
[22]. Vacheron, J., Desbrosses, G., Bouffaud, M. L., Touraine, B., Moënne-Loccoz, Y., Muller, D., & Prigent-Combaret, C. 2013. Plant growth-promoting rhizobacteria and root system functioning. *Frontiers in plant science*, *4*, 57135.
[23]. Fahad, S., Hussain, S., Bano, A., Saud, S., Hassan, S., Shan, D., & Huang, J. 2015. Potential role of phytohormones and plant growth-promoting rhizobacteria in abiotic stresses: consequences for changing environment. *Environmental Science and Pollution Research*, *22*, 4907-4921.
[24]. Shah, A., Nazari, M., Antar, M., Msimbira, L. A., Naamala, J., Lyu, D., & Smith, D. L. 2021. PGPR in agriculture: A sustainable approach to increasing climate change resilience. *Frontiers in Sustainable Food Systems*, *5*, 667546.
[25]. Etesami, H., & Adl, S. M. 2020. Plant growth-promoting rhizobacteria (PGPR) and their action mechanisms in availability of nutrients to plants. *Phyto-Microbiome in stress regulation*, 147-203.
[26]. Oleńska, E., Małek, W., Wójcik, M., Swiecicka, I., Thijs, S., & Vangronsveld, J. 2020. Beneficial features of plant growth-promoting rhizobacteria for improving plant growth and health in challenging conditions: A methodical review. *Science of the Total Environment*, *743*, 140682.
[27]. Sansinenea, E. 2019. Bacillus spp.: As plant growth-promoting bacteria. *Secondary metabolites of plant growth promoting rhizomicroorganisms: Discovery and applications*, 225-237.