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Effect of Pruning and Application of Plant Growth Promoting Rhizobacteria on Anthracnose Disease and Yield of Red Chili

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ABSTRACT

Red chili (*Capsicum annuum* L.) is a widely consumed, high-value horticultural crop in Indonesia, but its national productivity remains low at 9.59 tons.ha^{-1}, far below its potential due to factors such as disease, limited land, poor soil fertility, and suboptimal cultivation, highlighting the need for improved farming practices. Pruning can be implemented to promote branching and direct photosynthate to productive parts of the plant. The application of Plant Growth Promoting Rhizobacteria (PGPR) also presents a promising solution, as these microbes enhance nutrient uptake efficiency, stimulate plant growth through hormone production, and suppress pathogens such as the anthracnose-causing agent through antagonistic mechanisms and induced systemic resistance (ISR). Based on the research results, the combination of apical+water shoot pruning (P3) with the application of PGPR at 27.5 ml.L^{-1} (B3) significantly enhanced vegetative growth (plant height, number of leaves), accelerated flowering (39 days after planting), and increased fruit production (15 fruits per plant; 247.7 g per plant) in red chili variety HPT 1730, although the results remained below genetic potential due to environmental factors and anthracnose infection. The PGPR 27.5 ml.L^{-1} treatment also increased phenol content (3.10 mg.g^{-1}) and stomatal opening (71.30%), but was not yet effective in significantly suppressing anthracnose incidence.

Keywords: Anthracnose disease; *Capsicum annuum*; Growth and yield; PGPR; Pruning combinations

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INTRODUCTION

Red chili (*Capsicum annuum* L.) is one of the most widely consumed horticultural crops in Indonesia. It is commonly used as a spice and flavor enhancer in various dishes, particularly as the main ingredient in sambal (chili sauce). The demand for red chili in Indonesia continues to increase, especially in major cities with populations of over one million, reaching approximately 800,000 tons per year or 66,000 tons per month, with a 10–20% increase during major religious holidays (Wibisonya 2022). According to data from the BPS-Statistics Indonesia (2023) in 2022, the average productivity of red chili in Indonesia is around 9.59 tons/ha, which is still relatively low compared to its potential productivity of 15–20 tons.ha^{-1} (Ichwan et al. 2021).

One major factor contributing to this low productivity is the anthracnose disease, which can cause yield losses of up to 60%, and even 100% if not properly managed. Other contributing factors include limited land availability, low soil fertility, inefficient nutrient absorption, and suboptimal cultivation practices. These constraints result in low productivity and longer harvest times, reducing the profit margins for farmers (Sulistyowati 2019).

Implementing appropriate cultivation techniques is essential to maximize plant growth and yield. One such method is pruning, which involves cutting and removing plant parts that hinder growth. Pruning strengthens the plant stem and encourages more branching, which can lead to increased fruit production (Muntazar and Nurrachman 2019). Pruning also helps direct photosynthates efficiently to productive plant parts, optimizing growth and fruit yield. According to Yolanda et al. (2021), pruning the third branch at 21 days after planting resulted in the highest fruit weight per plant (409.89 g), compared to the control (311.78 g). Similarly, Sukmawati and Numba (2018) reported that water shoot pruning significantly improved the number of fruits (135.65 fruits/plant), fruit weight per plant (635.10 g), and fruit weight per plot (10.85 kg).

Plant Growth Promoting Rhizobacteria (PGPR) are beneficial bacteria that promote plant growth by enhancing nutrient uptake and acting as biostimulants through the production of phytohormones. PGPR directly stimulate plant growth through hormones such as gibberellins (GAs) and indole acetic acid (IAA) (Tabriji et

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al. 2016). Additionally, PGPR function as bioprotectants by suppressing pathogens, including the causal agents of anthracnose, through antagonistic mechanisms and Induced Systemic Resistance (ISR). These bacteria induce plant resistance by producing jasmonic acid (JA) and ethylene (ET) as signaling molecules (Zhu et al. 2022). The application of PGPR has proven effective in reducing anthracnose infection by up to 57.90% (Adiyatama et al. 2023).

PGPR also increase nutrient absorption efficiency, thus supporting better plant growth and yield. Chozin et al. (2020) found that combining 300 mL of PGPR per plant with 7.5 tons.ha^{-1} of compost significantly improved chili plant growth and yield, producing an average of 58.56 fruits per plant. PGPR can be sourced from various plant roots, such as bamboo, *Mimosa pudica*, and elephant grass. Bamboo root fermentation, in particular, contains microbes such as *Pseudomonas* sp. and *Bacillus* sp., which stimulate plant growth (Kuswati et al. 2023). The presence of *Pseudomonas fluorescens* colonies on bamboo roots also enhances phosphorus solubility in soil (Yulistiana et al. 2020).

This study aims to analyze the synergistic interaction between pruning and the application of Plant Growth Promoting Rhizobacteria (PGPR) in improving the growth and productivity of red chili plants (*Capsicum annuum* L.) under anthracnose disease infection. Specifically, this research is directed at examining the role of pruning in optimizing photosynthate distribution and how it interacts with hormonal regulation and the biocontrol activity of PGPR in suppressing the development of anthracnose disease and enhancing fruit yield. Furthermore, this study also aims to determine the most effective combination of pruning treatments and PGPR application in improving plant resistance and maximizing production under biotic stress conditions.

MATERIALS AND METHODS

Time and location

The research was conducted from May to December 2024 at the greenhouse, with laboratory analysis at the Plant Ecology and Production Laboratory, Faculty of Animal and Agricultural Sciences, Diponegoro University, Semarang.

Materials and methods

The materials used in this research were included 35 cm x 35 cm polybags, seedling trays, pruning shears, stakes, electron microscope, HPT 1730 red chili seeds, planting media, urea fertilizer, SP-36 fertilizer, KCl fertilizer, water, bamboo roots, granulated sugar, rice bran, shrimp paste, slaked lime, and other analytical materials. The research was conducted using a 4x4 factorial experiment based on a Completely Randomized Design (CRD). The first factor is pruning (P), consisting of four levels: P0 = Control/no pruning; P1 = Apical pruning; P2 = Water shoot pruning; P3 = Apical and water shoot pruning. The second factor is PGPR concentration (B), consisting of four levels: B0 = Control/no PGPR; B1 = PGPR 22.5 ml.L^{-1}; B2 = PGPR 25 ml.L^{-1}; B3 = PGPR 27.5 ml.L^{-1}. Each treatment combination was repeated 4 times and each experimental unit consisted of 2 plants, so there were 64 experimental units and resulting in a total of 128 plants.

The research stages consist of preparation, PGPR formulation and identification, anthracnose pathogen isolation and inoculation, seedling, transplanting, plant maintenance, implementation of pruning and PGPR treatments, harvesting, and data analysis. The PGPR used in this research was formulated by fermenting 250 g of bamboo roots soaked in 1 L of boiled and cooled water (±25°C) for 72 hours. This extract was combined with a boiled mixture of 0.5 kg bran, 0.5 kg shrimp paste, 1 tbsp lime, and 1 kg sugar, then filtered, homogenized, and incubated anaerobically in sealed plastic containers for 2–3 weeks. The PGPR solution was considered ready when it appeared clear, contained yellowish-white microbial biomass, and emitted a tape-like aroma (Daina et al. 2022). Bacterial identification was carried out by serial dilution of 1 mL of PGPR in sterile distilled water (10^{-1} to 10^{-5}), followed by spread plating of 0.1 mL on Pikovskaya's agar. Plates were incubated at room temperature for 24 hours. Colonies with distinct morphology were isolated, characterized macroscopically, and subjected to Gram staining. Biochemical tests were conducted, and identification was performed by referencing Bergey's Manual of Systematic Bacteriology (Vos et al. 2009) and the NCBI Taxonomy Database (Schoch et al. 2020).

Anthracnose pathogen was isolated from red chili fruits showing characteristic symptoms. Symptomatic tissues were surface-sterilized and cultured on potato dextrose agar (PDA), then incubated at room temperature for 3 days. *Colletotrichum* sp. was identified microscopically, purified, and propagated on PDA. Inoculation was performed via foliar spray at flowering (6 WAT) and fruiting (8 WAT) stages using a 10^7 CFU.mL^{-1} suspension (1.5 mL per plant) (Habibi and Wijayanto 2019).

Chili seeds were soaked for 10 minutes and sown individually in seedling trays. Seedlings with six true leaves were transplanted into polybags (one plant per bag). Standard horticultural practices were followed, including twice-daily watering, fertilization at 3, 6, and 9 weeks after transplanting (Urea, SP-36, KCl), manual weeding, and pest control through manual collection or insecticide application during high infestations. Apical pruning was conducted at 28 days after transplanting, and water shoots were periodically pruned using sterile scissors. PGPR application began at 2 weeks after transplanting and was applied weekly by drenching 300 mL per plant until the flowering stage (Chozin et al. 2020; Ichwan et al. 2021). Fruit harvesting started at 90 days after sowing and was carried out manually in three rounds at 4–5 day intervals. Parameters observed included plant height, number of leaves, number of branches, number of productive branches, time of first flower appearance, number of fruits per plant, fruit weight per plant, stomatal aperture, phenol content, and the intensity of anthracnose infection on red chili leaves and fruits.

Data analysis

Data were statistically analyzed using Analysis of Variance (ANOVA) 5%, then continued with the Duncan's Multiple Range Test (DMRT) 5%.

RESULT AND DISCUSSION

The water shoot pruning treatment had a significant effect on increasing plant height compared to the control and apical pruning and was not significantly different from the combined apical and water shoot pruning treatment. This indicates that water shoot pruning and combined apical and water shoot pruning treatments were effective in promoting vertical growth. The observed increase is presumed to result from reduced competition for nutrients and growth hormones due to water shoot pruning, allowing photosynthates to be more effectively allocated toward vertical development (Wilis 2023). The addition of apical pruning is suspected to disrupt apical dominance, thereby shifting red chili plant growth toward lateral branching and resulting in a broader plant structure. Cutting the apical part may inhibit auxin production, which in turn stimulates the emergence of lateral shoots (Yolanda et al. 2021).

The application of PGPR at a concentration of 27.5 mL.L^{-1} had a significant effect on increasing the height of red chili plants compared to the control, 22.5 mL.L^{-1}, and 25 mL.L^{-1} treatments. The plant height in the PGPR 27.5 ml.L^{-1} treatment reached 80.73 cm at 90 days after transplanting (DAT) indicating that 27.5 mL.L^{-1} is the optimal concentration for promoting vertical growth of red chili plants. The effectiveness of PGPR in enhancing plant height is presumed to be related to its ability to improve the availability and uptake of essential nutrients, particularly nitrogen (N), which plays a key role in vegetative growth. Nitrogen is generally absorbed by plant roots in the form of ammonium (NH_4^+), and PGPR contributes by fixing atmospheric nitrogen and converting it into forms that are more readily absorbed by plants (Asra et al. 2024).

The apical and water shoot pruning treatment had a significant effect on increasing the number of leaves compared to the control, apical pruning, and water shoot pruning. The number of leaves in the apical+watershoot pruning treatment reached 101 leaves at 90 days after transplanting (DAT), indicating that the combination of pruning methods effectively enhanced vegetative growth. This increase in leaf number is presumed to be associated with improved photosynthetic efficiency, which contributes to greater biomass accumulation and accelerated vegetative development (Yolanda et al. 2021). Furthermore, the simultaneous pruning of apical and water shoots may optimize the redistribution of growth hormones, such as auxin and cytokinin. Apical pruning reduces apical dominance by decreasing auxin production, thereby stimulating the growth of lateral shoots and promoting the development of more leaves (Kumar et al. 2020).

The application of PGPR at a concentration of 27.5 mL.L^{-1} had a significant effect on increasing the number of leaves of red chili plants compared to the control, 22.5 mL.L^{-1}, and 25 mL.L^{-1} treatments. At 90 days after transplanting (DAT), the number of leaves in the PGPR 27.5 ml.L^{-1} treatment reached 99 leaves. The increase in leaf number is presumed to be related to the presence of bacteria in the PGPR solution, such as *Pseudomonas fluorescens* and *Bacillus subtilis*, which are capable of stimulating plant growth through the production of growth hormones such as auxin and cytokinin (Chozin et al. 2020). Additionally, the increased physiological activity of the plants in response to PGPR application likely contributed to leaf formation. Microbial activity in mobilizing and providing essential nutrients to the plants is suspected to play a role in enhancing the photosynthesis rate, which ultimately supports biomass accumulation and leaf development (Husnihuda et al. 2017).

Table 1. Height and number of leaves

Pruning	PGPR (ml.L^{-1})				Average
	0	22.5	25	27.5	
	---------- Plant height (cm) ----------				
No pruning	51.90±2.72	54.79±2.83	56.54±4.27	68.01±4.85	57.81±7.17c
Apical pruning	51.35±4.02	62.55±3.36	69.8±4.86	77.25±5.74	65.24±10.69b
Water shoot	69.74±5.11	73.01±14.57	78.64±15.62	89.63±13.24	77.75±13.87a
Apical+watershoot	59.03±16.52	68.55±4.68	89.58±14.80	88.04±13.15	76.30±17.80a
Average	58.00±11.10c	64.73±10.02c	73.64±16.04b	80.73±12.75a	
	---------- Number of leaves ----------				
No pruning	56.50±6.49g	63.75±6.96fg	74.13±3.71ef	76.25±5.52ef	67.66±9.75c
Apical pruning	81.63±3.68de	87.13±5.23de	84.63±7.41de	103.00±17.36bc	89.09±12.34b
Water shoot	82,75±12.06de	91.25±11.38bcd	85.5±9.08de	90.63±7.82cd	87.53±9.86b
Apical+watershoot	80.13±3.99de	93.75±5.04bcd	104.38±11.30b	129.50±9.57a	101.94±20.03a
Average	75.25±13.01c	83.97±14.05b	87.16±13.51b	99.84±22.48a	75.25±13.01

Remark: Numbers followed by the same superscript in the same column, row, and interaction matrix indicate no significant difference at the DMRT level of 5%.

The combination of apical and water shoot pruning applied with PGPR at a concentration of 27.5 mL.L^{-1} resulted in a significantly higher number of leaves compared to the other treatments. This is presumed to be due to the more optimal allocation of plant resources for vegetative growth and improved nutrient absorption efficiency as a result of soil microbial activity. Apical and water shoot pruning allows for the optimization of photosynthesis by reducing non-productive parts of the plant, thus enabling more sunlight to be absorbed by the inner leaves (Sukmawati and Numba 2018). The combination of pruning with PGPR application produces a synergistic effect on plant growth, where pruning directs the allocation of resources toward productive plant parts, while PGPR helps enhance root system development, improves water absorption, and increases nutrient uptake efficiency (Sinaga et al. 2024).

The apical and water shoot pruning combined with PGPR 27.5 mL.L^{-1} showed the highest significant interaction effect on the number of branches and productive branches in red chili plants. Apical pruning enables the plant to produce more branches by eliminating apical dominance. The purpose of apical pruning is to remove apical dominance, thereby stimulating the growth of lateral shoots that will develop into new branches (Sucahyo and Wijayanto 2018). The addition of water shoot pruning further optimizes the allocation of plant energy for the formation of new branches. These new branches will eventually develop and produce flowers and fruits, thus becoming productive branches. The formation of flowers and fruits on chili plant branches is influenced by the availability of nutrients, especially phosphorus (P) and potassium (K). PGPR can assist in providing soluble phosphorus for plants, which can then be absorbed by the root system to support plant growth and development (Azzahra et al. 2021).

The time of first flower emergence in no pruning treatment was not significantly different from apical pruning treatment but was significantly longer compared to water shoot pruning and apical + water shoot pruning. Water shoot and apical + water shoot pruning treatments showed the best effects in accelerating flowering time, with an average of 39 days after transplanting (DAT). The effectiveness of water shoot and apical + water shoot pruning treatments in promoting earlier flowering is presumed to be due to water shoot pruning, which reduces non-productive plant parts and encourages earlier flower formation. Pruning is intended to reduce competition between vegetative and generative organs, and to focus on the allocation of assimilates to productive parts of the plant, particularly flower and fruit formation (Noviana et al. 2019). Pruning may also stimulate gibberellin hormone activity, which accelerates the flowering process. Plant growth is closely related to gibberellin hormones, which influence several stages of photosynthesis and flower development (Laksono 2018).

The time of first flower appearance in treatment 27.5 mL.L^{-1} did not differ significantly from 25 mL.L^{-1}, but was significantly earlier compared to 0 mL.L^{-1} and 22.5 mL.L^{-1}. Treatments 25 mL.L^{-1} and 27.5 mL.L^{-1} PGPR demonstrated the most favorable effects on floral initiation, with an average of 39 days after transplanting (DAT), indicating that PGPR concentrations between 25–27.5 mL.L^{-1} were more effective than lower concentrations in promoting flowering in red chili plants. The enhanced flowering response in these treatments is likely associated with the role of PGPR in solubilizing and increasing the availability of phosphorus (P), an essential macronutrient critical for reproductive growth. Phosphorus plays a vital role in floral development, fruit formation, seed development, and fruit abscission regulation (Simanjuntak 2024).

Table 2. Number of branches and number of productive branches

Pruning	PGPR (ml.L^{-1})				Average
	0	22.5	25	27.5	
	---------- Number of branches ----------				
No pruning	5.88±0.25i	7.25±0.65ghi	6.75±0.65hi	8.38±0.85fg	7.06±1.09d
Apical pruning	9.63±1.11def	10.50±0.82cd	11.38±0.63bc	10.63±0.75bcd	10.53±0.99b
Water shoot	8.13±0.48fgh	8.75±0.96efg	10.50±1.58cd	9.75±1.19de	9.28±1.38c
Apical+watershoot	10.88±0.48bc	11.50±0.58bc	12.00±0.71b	14.25±1.44a	12.16±1.54a
Average	8.63±2.01c	9.50±1.82b	10.16±2.28a	10.75±2.45a	
	---------- Number of productive branches ----------				
No pruning	5.00±0.41i	7.00±0.58h	7.00±0.91h	8.25±0.65fg	6.81±1.34d
Apical pruning	8.25±0.29fg	9.88±0.48bcd	10.88±0.63b	10.25±0.50bcd	9.81±1.09b
Water shoot	7.25±0.29gh	8.50±0.71ef	10.00±1.58bcd	9.63±1.03cde	8.84±1.43c
Apical+watershoot	9.38±0.25def	10.75±0.65bc	11.00±0.41b	12.88±0.95a	11.00±1.40a
Average	7.47±1.69d	9.03±1.56c	9.72±1.89b	10.25±1.88a	

Remark: Numbers followed by the same superscript in the same column, row, and interaction matrix indicate no significant difference at the DMRT level of 5%.

Table 3. Time of first flower appearance, stomatal aperture, and phenol content

Pruning	PGPR (ml.L^{-1})				Average
	0	22.5	25	27.5	
	---------- Time of first flower appearance (DAT) ----------				
No pruning	42.50±1.22	40.88±0.63	41.50±0.41	40.25±0.50	41.28±1.09a
Apical pruning	42.38±1.03	41.63±0.48	39.75±1.04	40.88±0.48	41.16±1.23a
Water shoot	40.00±0.71	39.75±0.50	38.75±0.50	38.63±0.85	39.28±0.86b
Apical+watershoot	40.25±0.65	39.88±0.48	39.00±0.71	39.13±1.03	39.56±0.85b
Average	41.28±1.46a	40.53±0.92b	39.75±1.28c	39.72±1.14c	
	---------- Stomatal aperture (%) ----------				
No pruning	58.06±7.05	58.71±7.76	60.91±8.36	62.05±8.76	59.93±7.36b
Apical pruning	56.67±9.34	62.22±5.44	58.71±7.76	70.47±7.61	62.02±8.75b
Water shoot	56.01±6.95	62.50±5.00	69.03±7.49	61.26±17.33	62.20±10.44b
Apical+watershoot	58.73±5.34	70.00±8.16	80.56±6.80	75.90±6.32	71.30±10.36a
Average	57.37±6.63b	63.36±7.37ab	67.30±11.17a	67.42±11.60a	
	---------- Phenol content (mg.gram^{-1}) ----------				
No pruning	2.68±0.29	2.72±0.30	3.16±0.38	2.83±0.05	2.85±0.32
Apical pruning	2.40±0.06	2.88±0.02	3.29±0.19	3.02±0.42	2.90±0.39
Water shoot	2.50±0.14	2.73±0.18	2.95±0.12	3.49±0.35	2.92±0.43
Apical+watershoot	2.57±0.12	2.71±0.13	3.20±0.55	3.57±0.58	3.01±0.55
Average	2.54±0.19b	2.76±0.18b	3.15±0.34a	3.23±0.48a	

Remark: Numbers followed by the same superscript in the same column, row, and interaction matrix indicate no significant difference at the DMRT level of 5%.

The highest stomatal aperture percentage was observed in the apical pruning combined with water shoot pruning treatment, reaching 71.30%, and was significantly higher than that of other treatments. This increase in stomatal opening is presumed to be associated with enhanced metabolic activity, particularly photosynthesis. A greater number of open stomata allows for higher CO_2 diffusion into the leaves, thereby increasing the photosynthetic rate (Sakoda et al. 2020). These findings suggest that the combination of apical and water shoot pruning effectively reduces intra-plant competition for assimilates and optimizes light interception. This improved physiological condition enhances both transpiration and photosynthesis processes. Optimal photosynthesis results in greater assimilate production, which is subsequently distributed to various plant organs to support growth and development (Novanursandy and Rachmawati 2023).

Pruning treatments did not exert a significant effect on the total phenolic content of red chili plants. Phenolic compounds are closely associated with antioxidant activity and serve as biochemical indicators of plant resistance to both biotic and abiotic stresses. These secondary metabolites are synthesized by plants in response to environmental stress conditions (Wiritania et al. 2024). The findings suggest that, under the conditions of this study, pruning did not directly influence the plant's resistance response nor its phenolic content. It is presumed that the pruning treatments applied were insufficient to trigger a metabolic response leading to increased phenolic synthesis. The biosynthesis of phenolic compounds in plants occurs via the shikimate pathway and phenylpropanoid metabolism (Rashid et al. 2018).

Application of PGPR at a concentration of 27.5 mL.L^{-1} resulted in a significantly higher total phenol content compared to the control and 22.5 mL.L^{-1} but was not significantly different from 25 mL.L^{-1}. Treatments 25 mL.L^{-1} and 27.5 mL.L^{-1} both recorded the highest phenol content at 3.10 mg.g^{-1}. These findings suggest that PGPR application has the potential to enhance phenolic compound accumulation in red chili plants. The inoculation of PGPR is presumed to stimulate secondary metabolic activity involved in phenol biosynthesis. PGPR has been reported to promote the production of secondary metabolites such as phenolic compounds and salicylic acid, which play a critical role in plant defence induction (Wijayanti 2018). Additionally, nitrogen availability influences amino acid synthesis, which serves as a precursor in the biosynthesis of phenolic compounds through the shikimic acid and phenylpropanoid pathways (Manik et al. 2019).

The combined pruning treatment of apical shoots and water shoots significantly increased both the number of fruits per plant and fruit weight per plant compared to the control and water shoot pruning alone but was not significantly different from apical shoot pruning alone. Similarly, PGPR application at a concentration of 27.5 mL.L^{-1} resulted in a significantly higher number of fruits and fruit weight per plant compared to the control and 22.5 mL.L^{-1}, but was not significantly different from 25 mL.L^{-1}. The highest fruit yield was observed in the combined treatment of apical+watershoot pruning and PGPR 27.5 mL.L^{-1} application, with an average of 15 fruits per plant and a total fruit weight of 247.7 g per plant.

Despite the improvement observed, the yield remained below the potential of the HPT 1730 red chili variety, which typically produces 66–88 fruits per plant with a total fruit weight of 1,198.33–1,525.00 g per plant. This discrepancy is likely due to suboptimal light intensity within the greenhouse, as the shading structure may have limited sunlight penetration. Reduced light availability can interfere with plant metabolism and slow photosynthetic rates, thereby affecting overall plant productivity (Ali and Cahyaningrum 2022). In addition, the deliberate inoculation with the anthracnose pathogen *Colletotrichum* sp. may have disrupted the physiological processes of red chili plants, particularly those related to fruit development. Anthracnose infection can damage plant tissues prior to the reproductive phase and impair essential functions such as respiration and photosynthesis, leading to reduced yield (Andriyani et al. 2020).

The combined treatment of apical and water shoot pruning with PGPR application at a concentration of 27.5 mL.L^{-1} resulted in the highest significant increase in both fruit number and fruit weight per plant. This outcome suggests a synergistic effect between pruning and PGPR application on fruit formation in red chili plants. The apical and water shoot pruning treatment likely promoted increased branching, thereby enhancing the potential for flower formation and subsequent fruit production. According to Pratama (2023), pruning in chili plants can increase the percentage of flowers that successfully develop into fruits by up to 1%, primarily due to the redirection of assimilates toward fruit development.

Furthermore, the inoculation of PGPR contributed to enhanced fruit set and biomass accumulation through improved nutrient uptake efficiency. PGPR has the ability to fix atmospheric nitrogen (N) and solubilize phosphate (P), which are essential for supporting flower and fruit development in chili plants (Jena and Agastya 2024). These findings indicate that the integration of pruning and PGPR treatment can serve as an effective agronomic strategy to increase the productivity of red chili under controlled cultivation conditions.

The pruning treatments and PGPR applications did not show a statistically significant effect on the intensity of anthracnose infection on the leaves and fruits of red chili plants. Although not statistically significant, PGPR treatments (22.5 ml.L^{-1}, 25 ml.L^{-1}, and 27.5 ml.L^{-1}) tended to reduce the severity of anthracnose on chili fruits compared to the control. Similarly, pruning treatments did not significantly influence disease severity, suggesting that the removal of foliage alone was insufficient to effectively suppress anthracnose incidence in this study. Pruning has been reported to help reduce anthracnose by decreasing canopy humidity, improving sunlight penetration, and enhancing field sanitation to inhibit pathogen development (Hartati et al. 2023). However, disease severity is also strongly influenced by environmental conditions conducive to pathogen proliferation, such as high humidity and relatively low temperatures (Rahman et al. 2022).

While statistical differences were not observed, PGPR application showed a trend toward lower anthracnose severity on both leaves and fruits. The lowest disease intensity on leaves was observed in the PGPR 25 ml.L^{-1} treatment (31.25%), whereas the lowest fruit disease intensity was found in the PGPR 27.5 ml.L^{-1} treatment (31.88%). These results suggest that PGPR has potential in suppressing anthracnose development, although the applied concentrations may not have been optimal for achieving statistically significant control. PGPR is known to induce plant defense mechanisms through induced systemic resistance (ISR), which involves structural and biochemical changes such as cell wall reinforcement that impede pathogen penetration. Previous studies have shown that PGPR application enhances the activity of defense-related enzymes, including peroxidase and salicylic acid, in response to pathogen infection (Mursiana et al. 2021).

Table 4. Number of fruits per plant and weight of fruits per plant

Pruning	PGPR (ml.L^{-1})				Average
	0	22.5	25	27.5	
	---------- Number of fruit per plant ----------				
No pruning	9.38±0.63d	10.50±0.91cd	9.88±1.55cd	10.00±0.41cd	9.94±0.96c
Apical pruning	12.38±2.50bc	10.38±0.48cd	13.25±3.40b	10.50±1.58cd	11.63±2.39ab
Water shoot	10.50±1.41cd	10.25±1.55cd	10.13±0.25cd	12.50±0.58bc	10.84±1.40bc
Apical+watershoot	10.50±1.29cd	12.00±0.71bcd	11.50±1.08bcd	15.88±2.81a	12.47±2.59a
Average	10.69±1.82b	10.78±1.15b	11.19±2.23ab	12.22±2.80a	
	---------- Weight of fruit per plant (gram) ----------				
No pruning	150.19±15.66d	165.76±13.21cd	162.54±25.54cd	162.20±7.08cd	160.17±16.18c
Apical pruning	197.25±38.92bc	168.63±7.68cd	219.79±57.04ab	168.98±27.11cd	188.66±40.01ab
Water shoot	171.49±24.13cd	165.14±26.19cd	174.15±20.54cd	201.39±13.10bc	178.04±24.03bc
Apical+watershoot	167.45±20.07cd	195.56±11.57bc	187.70±17.41bcd	247.70±39.33a	199.60±37.58a
Average	171.59±29.18b	173.77±19.53b	186.04±37.62ab	195.07±41.47a	

Remark: Numbers followed by the same superscript in the same column, row, and interaction matrix indicate no significant difference at the DMRT level of 5%.

Table 5. Intensity of anthracnose infection on red chili leaves and fruits

Pruning	PGPR (ml.L^{-1})				Average
	0	22.5	25	27.5	
	---------- Intensity of anthracnose infection on leaves (%) ----------				
No pruning	47.50±5.00	35.00±12.91	27.50±9.57	30.00±14.14	35.00±12.65
Apical pruning	47.50±15.00	27.50±17.08	35.00±12.91	37.50±12.58	36.88±14.93
Water shoot	37.50±15.00	32.50±9.57	27.50±9.57	35.00±12.91	33.13±11.38
Apical+watershoot	30.00±8.16	37.50±9.57	35.00±12.91	27.50±12.58	32.50±10.65
Average	40.63±12.89	33.13±11.95	31.25±10.88	32.50±12.38	
	---------- Intensity of anthracnose infection on fruits (%) ----------				
No pruning	45.00±12.91	40.00±8.16	25.00±12.91	32.50±9.57	35.53±12.63
Apical pruning	45.00±10.00	32.50±5.00	37.50±12.58	27.50±9.57	35.63±10.94
Water shoot	35.00±12.91	35.00±12.91	30.00±11.55	40.00±11.55	35.00±11.55
Apical+watershoot	42.50±17.08	27.50±15.00	37.50±5.00	27.50±9.57	33.75±13.10
Average	41.88±12.76	33.75±10.88	32.50±11.25	31.88±10.47	

Remark: Numbers followed by the same superscript in the same column, row, and interaction matrix indicate no significant difference at the DMRT level of 5%.

CONCLUSIONS AND SUGGESTIONS

The combination of shoot and water sprout pruning with the application of PGPR at 27.5 mL.L^{-1} significantly enhanced vegetative growth, including plant height and number of leaves, accelerated flowering, and increased fruit production in red chili variety HPT 1730, although the yield remained below its genetic potential due to environmental factors and anthracnose infection. The application of PGPR at 27.5 mL.L^{-1} was able to increase phenol content and stomatal opening but was not yet effective in significantly suppressing anthracnose infection.

Further research should be conducted in open-field conditions without shading to optimize the growth performance of red chili plants. Additionally, further optimization of PGPR concentration and formulation is necessary to achieve more significant improvements in crop productivity and pathogen suppression.

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