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Effectiveness of Plant Growth Promoting Rhizobacteria (PGPR) on the Growth of Coconut Seedlings Salak Genjah Variety

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Abstract
Coconut (Cocos nucifera L.) is a highly valued agricultural commodity in Indonesia. The Salak Dwarf variety is particularly popular among farmers due to its short harvest period and high productivity. To further enhance its potential, the use of Plant Growth-Promoting Rhizobacteria (PGPR) is being explored. PGPR are beneficial microorganisms that act as biofertilizers, improving plant growth through mechanisms such as nitrogen fixation, phosphate solubilization, and the production of growth hormones. This study aimed to evaluate the effectiveness of PGPR derived from bamboo roots on the growth of Salak Dwarf coconut seedlings. The research also sought to determine the optimal PGPR concentration for maximizing seedling growth. The experiment was conducted at the BSIP Tanaman Palma in North Sulawesi from January to May 2024. A Randomised Block Design (RBD) was used, with six treatments and three replications, totaling 18 experimental units. The treatments included a control (P0) with no PGPR and five PGPR concentrations (30, 60, 90, 120, and 150 ml/L). The key growth variables measured were plant height, leaf number, pseudo-stem girth, and leaf width. The results showed that bamboo root PGPR significantly influenced all measured growth parameters. The study concluded that the most effective concentration for promoting the growth of Salak Dwarf coconut seedlings was 60 mL/L. This finding highlights the potential of bamboo root PGPR as a natural, sustainable biostimulant to improve coconut cultivation.

Keywords: Growth of Seedlings; PGPR; Roots of Bamboo; Salak Genjah Coconut

INTRODUCTION

Coconut (Cocos nucifera L.) is a major plantation commodity that is vital to the Indonesian economy, making the country the largest coconut producer in the world (Directorate General of Plantations, 2023). One of the superior varieties that is increasingly in demand is the Genjah Salak coconut, which is known for its faster harvest characteristics and high productivity at a young age, making it an attractive choice for sustainable agricultural development (Sari et al., 2017). However, to achieve optimal production potential, the availability of high-quality and vigorous coconut seedlings from the early nursery phase is essential. Common challenges in nurseries include limited nutrient availability in the planting medium, susceptibility to pests and diseases, and the often slow growth rate of seedlings. These problems have traditionally been overcome by the use of chemical fertilizers and synthetic pesticides, which unfortunately can have a negative impact on soil fertility and the environment in the long term (Pranata et al., 2020).

As a more environmentally friendly and sustainable alternative, the use of beneficial soil microorganisms, especially Plant Growth Promoting Rhizobacteria (PGPR), is an innovative solution. PGPR is a group of bacteria that colonize the rhizosphere of plant roots and are able to stimulate plant growth through various mechanisms (Glick, 2012). These mechanisms include nitrogen fixation, phosphate solubilization, production of phytohormones such as auxins and gibberellins, and biocontrol capabilities against plant pathogens (Bashan & Bashan, 2010; Lugtenberg & Kamilova, 2009). A very promising source of PGPR that still requires further exploration is bamboo roots. The bamboo rhizosphere is known as a habitat rich in the diversity of beneficial microorganisms, because unique bamboo root exudates can trigger the growth and activity of PGPR bacterial populations (Setiawati et al., 2019; Wiyono et al., 2021).

PGPR isolates from bamboo roots have been shown to have the potential to increase the growth of various agricultural plants (Setiawati et al., 2019). Although the potential of bamboo root PGPR has been widely studied in other plants, its specific application to the growth of coconut seedlings, especially the Salak Genjah variety, has not been widely reported. The application of bamboo root PGPR is expected to be a biological solution to increase the vigor of coconut seedlings, reduce dependence on inorganic fertilizers, and support more sustainable cultivation practices. Therefore, this study was designed to test the effectiveness of various concentrations of bamboo root PGPR on the growth of Salak Genjah coconut seedlings, with the hope of identifying the optimum concentration that provides a significant positive effect.

One sustainable approach to increasing the growth of coconut seedlings is through the utilization of beneficial soil microorganisms, namely Plant Growth Promoting Rhizobacteria (PGPR). PGPR is a group of bacteria that live around the rhizosphere of plant roots and can stimulate plant growth through various mechanisms, such as nitrogen fixation, phosphate solubilization, phytohormone production, and pathogen biocontrol (Glick, 2012). A potential source of PGPR that has not been widely explored specifically for coconut is bamboo roots. The bamboo rhizosphere is known as a habitat rich in microorganism diversity, including PGPR, which are naturally associated with bamboo roots and can help nutrient absorption and plant resistance (Setiawati et al., 2019). The presence of unique bamboo root exudates was thought to support bacterial populations with the ability to stimulate plant growth (Wiyono et al., 2021). The utilization of PGPR from bamboo roots as a biostimulant agent in Salak Genjah coconut seedlings was expected to be an environmentally friendly alternative to increase seedling vigor, reduce dependence on inorganic fertilizers, and ultimately support sustainable coconut cultivation. Therefore, this study was designed to test the effectiveness of PGPR isolated from bamboo roots on the growth of Salak Genjah coconut seedlings.

Based on the background above, the formulation of the problem in this study is: (1) is the application of bamboo root PGPR able to increase the vegetative growth of coconut seedlings (*Cocos nucifera* L.) of the Genjah Salak variety?; (2) what is the optimal concentration of bamboo root PGPR in increasing the growth of coconut seedlings of the Genjah Salak variety?

The objectives of this study are: (1) to determine the effect of bamboo root PGPR application on the vegetative growth of coconut seedlings (Cocos nucifera L.) of the Genjah Salak variety; (2) to determine the most effective concentration of bamboo root PGPR in increasing the growth of coconut seedlings of the Genjah Salak variety. The expected benefits of this research are: (1) for Coconut Farmers: Providing information and recommendations on sustainable coconut cultivation technology innovations by utilizing bamboo root PGPR, to improve seed quality and reduce the use of chemical fertilizers; (2) for the Agricultural Industry: Providing a scientific basis for the development of bamboo root PGPR-based biofertilizer products that are specific for coconut plants, opening up market opportunities for environmentally friendly agricultural products; (3) for the Environment: Encouraging more environmentally friendly agricultural practices by reducing greenhouse gas emissions and soil pollution due to the use of synthetic fertilizers, and supporting soil microbial biodiversity.

Literature Review

Coconut (Cocos nucifera L.) serves as a vital plantation crop in tropical areas, such as Indonesia, possessing significant economic worth and playing a key role in supplying food and industrial raw materials (Badan Pusat Statistik, 2023). The Salak Dwarf Coconut is a coconut type recognized for its early yield and slow growth, rendering it appealing for plantation cultivation (Suryanto & Lestari, 2021). To enhance its productivity potential, robust seedlings with strong initial growth are necessary. The availability of nutrients and suitable environmental conditions greatly influence the growth and productivity of plants, such as coconuts (Smith & Johnson, 2020). Numerous initiatives have been undertaken to enhance seedling development to guarantee sustainable production in the future (Davis et al., 2018). A promising method involves the utilization of microorganisms that enhance plant growth, referred to as Plant Growth Promoting Rhizobacteria (PGPR) (Gupta & Singh, 2017).

Plant Growth Promoting Rhizobacteria (PGPR) are bacteria found in the soil that inhabit the area near or on the surface of roots. They participate in encouraging plant growth and development either directly or indirectly by producing and releasing different growth-regulating substances in the rhizosphere (root region). These rhizobacteria promote growth by assisting plants in obtaining nutrients like nitrogen, phosphorus, and various necessary minerals. They also adjust levels of plant hormones. Furthermore, they serve as biocontrol agents by diminishing or obstructing the growth of soil pathogens. The figure illustrates the mechanism of action of PGPR (Ahemad & Kibret, 2014; Backer et al., 2018; Chandran et al., 2020; Shah et al., 2021) (Figure 1).

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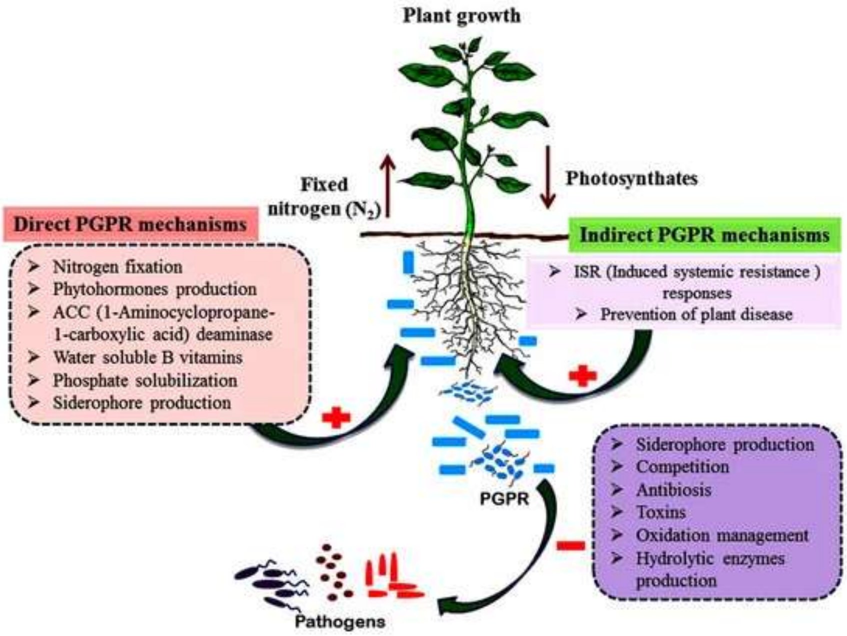

Figure 1. Mechanism of PGPR (Chandran, et.al., (2020)

A significant amount of research has been undertaken on the use of PGPR in different agricultural and horticultural crops, revealing diverse outcomes influenced by the PGPR type, application concentration, plant species, and environmental factors (Nurhayati et al., 2022). Numerous studies have indicated notable increases in plant height, biomass, leaf count, and stem width following PGPR treatment (Aziz & Rahman, 2021). For instance, a study by Dewi and Santoso (2019) found that the use of PGPR notably enhanced the growth of cocoa seedlings. Arfandi (2019) found in his research on soybean plants that the application of PGPR influenced the growth and yield of these plants, with the use of PGPR derived from bamboo roots yielding the most favorable outcomes in terms of leaf count, base count, pod count, pod weight per plant, weight of 100 seeds per plot, and seed weight per plot. Marom et al. also observed positive effects during the pod formation stage (30 HST to 45 HST), on mean flowering age, wet weight of pods for each cluster, dry weight of pods per cluster, weight of 100 seeds, and dry pod yield per hectare.

The evaluation of various PGPR isolates to enhance shallot yield in coastal sandy regions, as reported by Tuhuteru et al. (2019), indicated that multiple PGPR isolates examined were capable of producing IAA, with the highest concentration observed in isolate BrSG.5 (*Burkholderia seminalis*) when paired with three cultivars (22.46 mg kg-1, 28.61 mg kg-1, 41.41 mg kg-1). Isolate BP25.2 (*Bacillus methylotrophicus*) successfully produced N (0.05%), whereas isolate BP25.7 (*Bacillus subtilis*) was efficient in generating residual P (0.22 ppm). Sutariati et al. also conducted tests on PGPR isolates, concluding in their research that most PGPR isolates obtained from the rhizosphere of healthy rice across four districts in Southeast Sulawesi had the capacity to solubilize phosphate and fix nitrogen. The isolates PKNW 6, PKMN 7, PKNS 3, PKNS 9, and PKNW 4 exhibited superior abilities to dissolve phosphate and nitrogen compared to the other isolates.

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A study by Salamiah and Wahdah (2015) on PGPR application for tungro disease management in local rice in South Kalimantan found that among 15 PGPR isolates tested, 5 demonstrated potential as biological agents to activate the plant's defense mechanisms against tungro dues to their ability to produce adequate levels of HCN and solubilize phosphate. Three samples were collected for testing in the field. The findings indicated that the use of PGPR did not effectively control tungro infestations in local rice; however, one specific PGPR (*Pseudomonas fluorescens* isolate 2) successfully reduced tungro attacks on Inpara-4 and 5 rice varieties.

METHODS

Research Time and Location

The study was carried out between January 2024 and May 2024. The study was conducted at the Palm Plant Research Institute (BSIP Palma) in Mapanget, North Sulawesi.

Supplies and Tools

The study materials comprised Salak variety coconut (Cocos nucifera L.) seedlings, propagated bamboo root PGPR (the isolated source was pre-prepared), water, a planting medium (a soil and sand mixture in specific ratios, following coconut nursery guidelines), and basal fertiliser, if needed. The tools utilised comprised polybags, a digital scale, a ruler/tape measure, a vernier calliper, a sprayer, stationery, a camera, and additional gardening implements.

Experimental Design

This study was conducted in an RBD of six treatments with three replications. The total number of experimental units was 6 × 3 = 18 (6 treatments × three replicates). There were five coconut seedlings per experiment essay unit and a total of 90 seedlings. Arrangement of experimental units in a block was random in order to alleviate the impact of environmental heterogeneity. The PGPR concentration treatments were: P0 = 0 ml/L; P1 = 30 ml/L; P2 = 60 ml/L; P3 = 90 ml/L; P4 = 120 ml/L; P5 = 150 ml/L. Seedling Setup and PGPR Utilisation Salak Dwarf coconut seedlings, four months post-germination, were chosen for the study under consistent conditions. The seedlings were placed in polybags filled with growing medium. The application of PGPR occurred one week following the planting of the seedlings in the polybags. The PGPR solution at the correct concentration was applied to the growing media surrounding the seedling roots with a consistent volume per seedling (for instance, 200 ml per seedling), administered biweekly during the study duration.

This research was conducted over a four-month period, from January 2024 to May 2024. The research location was the Palm Plant Research Institute (BSIP Palma) in Mapanget, North Sulawesi.

Materials and Equipment

The research materials included coconut (Cocos nucifera L.) seedlings of the Salak variety, isolated and propagated bamboo root PGPR (the isolate source was prepared beforehand), water, planting medium (a mixture of soil and sand in specific proportions, according to coconut nursery standards), and basal fertiliser, if necessary. The equipment used included polybags, a digital scale, a ruler/tape measure, a vernier calliper, a sprayer, stationery, a camera, and other gardening tools.

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Experimental Design

This research used a Randomised Block Design (RBD) with six treatments and three replications. The total number of experimental units was 18 (6 treatments × three replications). Each experimental unit consisted of five coconut seedlings, resulting in a total of 90 seedlings. The placement of experimental units in blocks was arranged randomly to minimise the influence of environmental heterogeneity. The treatment of PGPR concentration consist of : P0 = 0 ml/L; P1 = 30 ml/L; P2 = 60 ml/L; P3 = 90 ml/L; P4 = 120 ml/L; P5 = 150 ml/L

Seedling Preparation and PGPR Application

Salak Dwarf coconut seedlings, 4 months old from germination, with uniform conditions were selected for the study. The seedlings were planted in polybags containing growing media. PGPR application was carried out one week after planting the seedlings in the polybags. The PGPR solution with the appropriate concentration was watered onto the growing media around the seedling roots with a uniform volume per seedling (e.g., 200 ml per seedling), applied every 2 weeks throughout the study period.

Variables Observation

Observations were conducted every two weeks until the end of the study in May 2024. The observed variables included: (1) Plant Height (cm): Measured from the base of the pseudostem to the tip of the longest fully opened leaf using a tape measure (Aprianis et al., 2017); (2) Number of Leaves (leaflets): Counted the number of fully opened leaves on each seedling (Wibowo et al., 2019); (3) Pseudostem Circumference (cm): Measured the diameter of the base of the pseudostem using a vernier caliper, then converted to circumference or directly measured the circumference (Riyanti et al., 2018); (4) Leaf Width (cm): Measured the width of the widest leaf when the leaf is fully opened (Sari et al., 2017).

Data Analysis

Data were analyzed using Analysis of Variance (ANOVA) at a test level of 5%. If the test results using the F test are significant, continue with the mean difference test using the BNT Test (Least Significant Difference) at the 5% level.

RESULTS AND DISCUSSION

The results indicated that the application of bamboo root PGPR (Plant Growth-Promoting Rhizobacteria) at various concentrations had a significant impact on the growth of Salak dwarf coconut seedlings. This effect was observed across all measured growth parameters, including plant height, number of leaves, pseudostem circumference, and leaf width. In general, coconut seedlings that were treated with PGPR showed superior growth when compared to the control seedlings (0 ml/L), which were not subjected to the PGPR treatment. Different vegetative growth metrics were evaluated 84 days post-planting (DAP), and the findings are presented in Table 1.

Table 1. Effect of bamboo root PGPR concentration on seedling height, number of leaves, pseudostem circumference, and leaf width of Salak dwarf coconut seedlings at 84 DAP.

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Treatment	Seedling Height (cm)	Number of Leaves	Pseudostem Circumference (cm)	Leaf Width (cm)
0 ml/L	85.46 a	5.80	10.46 a	14.90 a
30 ml/L	96.66 b	6.00	12.10 b	16.00 b
60 ml/L	101.96 c	6.00	12.46 b	16.53 b
90 ml/L)	100.50 c	6.00	11.60 b	16.10 b
120 ml/L	100.26 c	6.00	11.80 b	15.60 b
150 ml/L	96.46 bc	6.00	11.80 b	15.30 b
BNT 0.05	4.40	-	0.72	0.71

Description: Numbers followed by the same letter in the same column are not significantly different according to the BNT test at the 5% level.

Seedling Height

The analysis results indicated that the application of bamboo root PGPR significantly influenced the height of Salak Dwarf coconut seedlings at 84 days after planting. The treatment with a concentration of 60 ml/L (P2) resulted in the tallest seedlings, measuring 101.96 cm, which was significantly different from the control treatment (P0), where seedlings measured 85.46 cm. Other treatments with concentrations of 30 ml/L, 90 ml/L, and 120 ml/L also showed an increase in seedling height compared to the control. However, the treatment with the highest concentration of 150 ml/L began to exhibit a decline in performance when compared to the 60 ml/L, 90 ml/L, and 120 ml/L treatments.

The increase in seedling height from PGPR application is generally attributed to the bacteria's ability to produce phytohormones, such as auxin and gibberellin (Glick, 2012). Auxin plays a crucial role in cell elongation and tissue differentiation, while gibberellin is involved in stem elongation and overall plant growth (Vacheron et al., 2013). PGPR isolates from the bamboo rhizosphere have been reported to produce auxin, which directly contributes to increased plant height (Setiawati et al., 2019). Additionally, PGPR can enhance the availability and uptake of essential nutrients, such as nitrogen and phosphorus, from the growing medium. Nitrogen is a major component of proteins and chlorophyll, which are vital for vegetative growth and photosynthesis, while phosphorus is essential for energy transfer and strong root development (Meena et al., 2020). Improved nutrient availability enables seedlings to allocate more energy toward vertical growth.

Interestingly, treatments with excessively high PGPR concentrations (150 ml/L) showed a decrease in seedling height compared to the optimal concentration (P2). This suggests a threshold effect or potential toxicity at excessive doses, as well as possible unfavorable changes in microbial community dynamics (Bashan et al., 2014).

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Leaf Number

The findings concerning leaf count indicated no notable difference between the PGPR treatments and the control group at 84 days after-planting. The majority of treatments resulted in an average of 6.00 leaves, whereas the control yielded an average of 5.80 leaves. Even though these differences were not statistically significant, a clear trend of increased leaf count was observed in all PGPR treatments when compared to the control.

Although the rise in leaf count in the PGPR treatments wasn't statistically significant, it might indicate an early stimulation of new leaf development, which could become more noticeable in subsequent growth stages or with longer observation times. Cytokinin-producing PGPRs can encourage cell division and shoot differentiation, which may result in enhanced leaf development (Kumari et al., 2015). Moreover, the improved nutrient absorption efficiency, particularly of nitrogen, by PGPR may foster chlorophyll and protein production, both vital for proper leaf growth (Chaudhary et al., 2021). The absence of major differences might suggest that at this point, the leaf count in the coconut seedlings had leveled off, or that the impact of PGPR was more evident on biomass and root strength rather than on leaf numbers during this time.

Pseudo-Stem Twisting

The use of bamboo root PGPR notably impacted the pseudo-stem twisting of Salak Dwarf coconut seedlings. The application of 60 ml/L led to the most significant twisting of the pseudo-stem, recorded at 12.46 cm, which was notably higher than the control group's measurement of 10.46 cm. The treatments of 30 ml/L, 90 ml/L, 120 ml/L, and 150 ml/L showed more pseudo-stem twisting than the control (0 ml/L), but no significant differences were observed among the various PGPR treatment groups (30 ml/L to 150 ml/L).

Greater twisting of the pseudo-stem signifies enhanced biomass accumulation and overall seedling health. Bulkier stems indicate enhanced vascular tissue development, vital for the transportation of water and nutrients (Zaidi et al., 2018). This phenomenon can be linked to the capability of PGPR to improve nutrient uptake, especially phosphorus. Phosphorus is essential for tissue development and cell structure, and it also aids in the synthesis of phytohormones that promote the growth and division of parenchymal cells in the cambium (Goldstein et al., 2008). Seedlings that possess a greater pseudo-stem thickness are generally sturdier and better able to withstand mechanical and environmental challenges during transplantation.

Leaf Width

The leaf width of Salak Dwarf coconut seedlings was significantly influenced by the application of bamboo root PGPR (Plant Growth-Promoting Rhizobacteria). The treatment with 60 ml/L demonstrated the largest leaf width at 16.53 cm, which was notably different from the control measurement of 14.90 cm. Similar to the pseudostem circumference, all PGPR treatments ranging from 30 ml/L to 150 ml/L resulted in greater leaf widths compared to the control, though no significant differences were observed among these treatments. The increase in leaf width suggests an expansion of the seedlings' photosynthetic surface area. Wider leaves enhance light capture, which in turn increases the rate of photosynthesis and the production of assimilates needed for growth (Glick, 2012).

Adequate nutrient availability, particularly nitrogen, facilitated by PGPR, plays a vital role in chlorophyll and protein synthesis, supporting the development of leaf cells (Chaudhary et al., 2021). Additionally, the production of phytohormones by PGPR can stimulate the growth and expansion of leaf cells (Egamberdieva et al., 2017). Therefore, larger leaf widths indicate that seedlings are more efficient at converting light energy into biomass. Overall, the results of this study indicate that bamboo root PGPR has significant potential as a biostimulant for enhancing the growth of Salak Dwarf coconut seedlings. The optimal concentration identified was 60 ml/L of water (P2), which consistently provided superior performance in terms of seedling height, pseudostem circumference, and leaf width. While the number of leaves did not show a statistically significant difference at 84 days, these findings align with previous research demonstrating the potential of PGPR from the bamboo rhizosphere to enhance plant growth (Setiawati et al., 2019; Wiyono et al., 2021).

The presence of specific PGPR in the bamboo rhizosphere, which are capable of fixing nitrogen, solubilising phosphate, and producing phytohormones, is essential for increasing coconut seedling vigour (Bashan et al., 2014; Vacheron et al., 2013). The application of bamboo root PGPR at this optimal concentration could represent an environmentally friendly and sustainable strategy for coconut nursery practices, reducing reliance on chemical fertilisers and enhancing the quality of seedlings ready for field planting. Further research may be required to identify the specific PGPR species in bamboo root isolates and to understand the underlying molecular interaction mechanisms.

CONCLUSION

The research findings indicate that using PGPR (Plant Growth Promoting Rhizobacteria) sourced from bamboo roots considerably improved the growth of Salak Dwarf coconut (Cocos nucifera L.) seedlings. The parameters assessed, including plant height, leaf count, pseudostem circumference, and leaf breadth, showed a favorable reaction to the PGPR treatment.

The best concentration of PGPR derived from bamboo roots for enhancing the growth of Salak Dwarf coconut seedlings was determined to be 60 ml/L of water. This concentration consistently produced better growth performance than both the control treatment and other PGPR levels.

The results of this research suggest using PGPR from bamboo roots at a concentration of 60 ml/L of water as a successful method to enhance the growth of Salak Dwarf coconut seedlings in nurseries.

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