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Effects of Trichoderma spp. Application and Immersion Duration on the Growth Performance of Black Pepper (*Piper nigrum* L.) Cuttings

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ABSTRACT

The study aims to determine the effect of Trichoderma sp. application on the growth of pepper shrub seedlings, to determine the duration of Trichoderma sp. immersion on the growth of pepper shrub seedlings and to determine the interaction between Trichoderma sp. and the duration of immersion on the growth of pepper shrub seedlings. This study was conducted using a 2-factor Randomized Block Design with a factorial pattern, the first factor being the provision of Trichoderma sp. and coconut water and the second factor being the duration of soaking the pepper cuttings. The observed parameters were the time of shoot emergence, shoot length, number of shoots, number of leaves, shoot stem diameter, root volume and percentage of cutting success. The results showed that the application of Trichoderma sp. 15 g + 25% coconut water gave the best results on the time of shoot emergence 35.9 days after planting, shoot length 15.5 cm, number of leaves 4.8 pieces, root volume 5.67 ml and percentage of cutting success 87.5%. The 12-hour soaking time gave the best results on the time of emergence of shoots 32.7 days after planting, root volume 5.33 ml and percentage of successful cuttings 87.5%. The interaction between the provision of Trichoderma sp. and the soaking time did not have a statistically significant effect, but showed the highest average value in the treatment of Trichoderma sp 15 g + 25% coconut water with a soaking time of 12 hours, namely on the parameters of the time of emergence of shoots 29.4 days after planting, shoot length 17.1 cm, number of leaves 5.3 strands, stem diameter 0.14 mm and percentage of successful cuttings 100%.

INTRODUCTION

Pepper (*Piper nigrum* L.) is an important spice crop in Indonesia. Pepper is a leading commodity in the plantation sub-sector and has significant potential to increase the country's foreign exchange earnings. Foreign exchange earnings from pepper rank fourth after palm oil, rubber, and coffee. This commodity contributes significantly to Indonesia's exports, with the majority of national pepper production destined for foreign markets. In addition to contributing to foreign exchange, pepper also contributes significantly to employment, industrial raw materials, and farmers' income (Siswanto et al., 2021). According to the Directorate General of Plantations (2020), cocoa plants in Indonesia are still experiencing a decline from 2019 total production of 783,987 tons to 2020 around 739,483 tons. This is still very low considering that Indonesia is the third largest producer in the world. The causes of this condition are poor selection of planting materials, less than optimal cultivation techniques, old plants, and problems with attacks by plant-disturbing organisms (OPT) (Keytimu, 2023). The vegetative propagation technology most widely applied by cocoa farmers is grafting. This technology is easy to do, the materials used are easy to obtain, and the cost is cheap. Grafting is a plant propagation technique by combining the rootstock of a selected and adaptive parent tree in the local area with the scion of a superior variety that produces high yields. Grafting is also intended to improve the properties of the scion and obtain plants that produce quickly (Naim & Sirdam, 2022).

However, pepper cultivation by farmers generally uses climbing pepper plants. Climbing pepper plant cultivation requires climbing poles, thus incurring higher production costs. Furthermore, climbing poles are currently increasingly limited in availability. One possible solution is to switch to growing shrub pepper plants because shrub pepper does not have clinging climbing tendrils, so its cultivation does not require climbing poles. Furthermore, shrub pepper has several advantages such as more practical maintenance and

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harvesting, as well as earlier and continuous fruiting (Maryani, 2018).

Various types of plant pests (OPT) are found in pepper plants, both insect pests and diseases, and are a significant obstacle in pepper cultivation. To increase crop yields, the use of organic fertilizers that can inhibit the growth of fungi that cause plant diseases and increase nutrient content in the soil is an alternative solution, namely the use of Trichoderma sp. Trichoderma sp. has been widely used as a decomposing organism (bio decomposer) that can inhibit the growth of several fungi that cause plant diseases. The use of Trichoderma sp. can accelerate the decomposition of organic matter by reducing organic carbohydrates, especially cellulose, with the help of cellulase enzymes, namely cellubiose and chitinase (Hartati et al., 2016). Trichoderma sp. can also have a positive effect on shoot length, shoot number, and leaf number of pepper seedlings, accelerating the time for shoot emergence (Syam et al., 2021).

The growth of pepper cuttings can be stimulated using natural hormones, including auxin found in Trichoderma sp. and coconut water. Adequate auxin levels in cuttings can influence root growth. According to Tarigan et al. (2017), low auxin levels can be caused by low concentrations, requiring a longer soaking time, typically 12 hours.

MATERIALS AND METHODS

The study was conducted in BTP Block H, Tamalanrea District, Makassar City, Indonesia (5°07′S; 119°30′E), from May to July 2025. The site represents a lowland tropical environment with average daily temperatures ranging from 26–32 °C and relative humidity of 70–85%.

The plant material used in this experiment was chili pepper (Capsicum annuum L.) cultivar Natar 1. The growth medium consisted of topsoil, well-decomposed cattle manure, and rice husk in a 2:1:1 (v/v) ratio. The medium was homogenized and air-dried prior to use. Polybags (15 cm × 20 cm) were filled with 2 kg of the prepared medium. Plants were grown under paranet shading (50% light intensity) to reduce excessive solar radiation.

The bio stimulant treatment consisted of Trichoderma sp. inoculum (commercial formulation) applied at a dose of 15 g per treatment solution. Fresh coconut water was filtered and added at a concentration of 25 g per solution where applicable. The treatments were prepared by dissolving Trichoderma sp. in distilled water, with or without coconut water, to obtain homogeneous suspensions.

The experiment employed a two-factor randomized complete block design (RCBD). The first factor was the soaking solution, consisting of three levels, Control (no Trichoderma sp. and no coconut water), 15 g Trichoderma sp. in water, and 15 g Trichoderma sp. + 25 g coconut water. The second factor was soaking duration with three levels: 6 h, 9 h, and 12 h. A total of nine treatment combinations were obtained and each treatment was replicated four times, resulting in 36 experimental units. Each experimental unit consisted of one polybag containing one chili pepper seedling.

Chili pepper seeds were surface-sterilized using 1% sodium hypochlorite for 2 min and rinsed thoroughly with distilled water. Seedlings were raised in nursery trays for 14 days. Uniform seedlings were then subjected to soaking treatments according to the experimental design before transplanting into polybags. After soaking, seedlings were transplanted immediately to minimize physiological stress.

Data were analyzed using two-way analysis of variance (ANOVA) to determine the effects of soaking solution, soaking duration, and their interaction. When significant differences were detected ($p < 0.05$), mean comparisons were performed using the Least Significant Difference (LSD) test at the 5% significance level. All statistical analyses were conducted using Excel.

RESULTS AND DISCUSSION

1. Time for shoots to appear

The results of observations and analysis of variance showed that the application of Trichoderma sp. and the soaking time had a very significant effect, but the interaction between Trichoderma sp. and soaking time did not have a significant effect on the time of shoot emergence in pepper plant seedlings.

Table 1. The average time for shoots to appear for pepper plant seedlings is 12 WAP when Trichoderma sp. is applied and the soaking time is long.

Trichoderma sp.	Long soaking time/O'clock			Average
	6	9	12	
Control (T0)	45.88	43.05	38.83	42.58[a]
Trichoderma sp. 15 g + water	42.00	40.95	38.88	40.61[ab]
Trichoderma sp. 15 g + coconut water 25%	40.25	38.00	29.40	35.88[b]
Average	42.71[x]	40.67[xy]	35.70[y]	
LSD 5%		6.44		

Note: Numbers followed by different letters in the same row (a, b and c) and column (x, y and z) are significantly different at the LSD 5% test level.

The results of the LSD 5% test in Table 1 show that the application of 15 g of Trichoderma sp. + 25% coconut water (T2) resulted in the fastest shoot emergence time of 35.88 day after planting (DAP). significantly different from the control treatment (T0) with a shoot emergence time of 42.58 DAP. However. this difference was not statistically significant compared to the 15 g of Trichoderma sp. + water treatment (T1) with a shoot emergence time of 40.6 DAP. The longest average shoot emergence time was obtained in the control treatment (T0). at 42.58 DAP. and was not significantly different from the 15 g of Trichoderma sp. + water treatment (T1).

A 12-hour soaking period (D3) resulted in the fastest shoot emergence time of 35.7 DAP. significantly different from the 6-hour soaking treatment (D1) with a shoot emergence time of 42.7 DAP. However. this difference was not statistically significant compared to the 9-hour soaking treatment (D2) with a shoot emergence time of 40.6 DAP. The longest average time for shoot emergence was obtained in the 6-hour immersion treatment. namely 42.7 DAP and was not significantly different from the 9-hour immersion treatment (D2).

The evaluation of shoot emergence time following bio stimulant application provides important insights for agricultural practices. particularly in efforts to optimize seed germination and seedling vigor. The results showed that the application of 15 g of Trichoderma sp. combined with 25% coconut water (Treatment T2) produced the fastest shoot emergence. with an average of 35.88 hours after sowing (HAS). compared to the control treatment (T0). which exhibited a slower emergence time of 42.58 HAS. These findings indicate that the combination of Trichoderma sp. and coconut water positively influences physiological processes associated with seed germination and early plant development. potentially through enhanced nutrient uptake and beneficial microbial interactions that support healthier seedling growth (Wei et al., 2024; Mandang, 2017).

However, although T2 showed a clear improvement compared to T0. it did not differ significantly from the treatment using 15 g of Trichoderma sp. with water only (T1). which had an average shoot emergence time of 40.6 HAS. This supports the notion that coconut water. as a natural bio stimulant rich in nutrients and plant growth hormones. may enhance the effects of beneficial fungi such as Trichoderma sp. (Benaseer et al., 2017; Sudaryono. 2019). Coconut water contains cytokinin that stimulate cell division and cell enlargement. which may explain the faster shoot emergence observed in T2 (Konan et al., 2012). The absence of a statistically significant difference between T1 and T2 suggests that the growth-promoting effect of Trichoderma sp. alone may already be sufficiently strong. or that the additional application of coconut water does not provide a substantial incremental benefit over Trichoderma sp. alone (Gopal et al., 2019).

Seed soaking duration had a significant effect on shoot emergence time. The 12-hour soaking treatment (D3) resulted in the best average emergence time of 35.7 HAS. which was considerably faster than the 6-hour soaking treatment (D1). which showed an emergence time of 42.7 HAS. The 12-hour soaking treatment not only produced the most favorable results but was also statistically different from the other treatments. In contrast. the 9-hour soaking treatment (D2). with an average emergence time of 40.6 HAS. did not show a statistically significant difference compared to D3.

Longer soaking duration is thought to facilitate more optimal water imbibition and enable germination processes to initiate more efficiently. given that water plays a critical role in activating seed metabolism and in enhancing the uptake of growth-promoting compounds present in Trichoderma sp. and coconut water (Aliwarga et al., 2023; Konan et al., 2012; Putra et al., 2022).

Conversely. the 6-hour soaking treatment resulted in the longest shoot emergence time. indicating that insufficient soaking leads to suboptimal seed hydration and consequently slower germination. This finding is consistent with previous studies emphasizing the importance of appropriate soaking duration to improve seed viability. germination speed. and overall plant health. highlighting the need for a balance between soaking time and the physiological condition of the seeds (Sukorini et al., 2021; Konan et al., 2012).

2. Shoot Length

The results of observations and analysis of variance showed that the application of Trichoderma sp. had a very significant effect. while the treatment of soaking time and the interaction between Trichoderma sp. and soaking time did not have a significant effect on the length of shoots in pepper plant seedlings.

Table 2. Average shoot length (cm) of pepper plant seedlings during 12 weeks after planting with Trichoderma sp. application and soaking time

Trichoderma sp.	Long soaking time/O'clock			Average
	6	9	12	
Control (T0)	7.63	9.38	10.10	9.03[b]
Trichoderma sp. 15 g + water	10.75	12.28	12.03	11.68[ab]
Trichoderma sp. 15 g + coconut water 25%	14.08	15.30	17.08	15.48[a]
Average	10.82	12.32	13.07	
LSD 5%	5.44			

Note: Numbers followed by different letters in the same row (a, b and c) are significantly different at the LSD 5% test level.

The results of the LSD 5% test in Table 2 show that the application of Trichoderma sp. 15 g + 25% coconut water (T2) provided the highest shoot length of 15.48 cm. which was significantly different from the control treatment (T0) with a shoot length of 9.03 cm. but this difference was not statistically significant compared to the treatment of Trichoderma sp. 15 g + water (T1) with a shoot length of 11.68 cm. The lowest average shoot length was obtained in the control treatment (T0). which was 9.03 cm and was not significantly different from the treatment of Trichoderma sp. 15 g + water (T1).

This study highlights the effects of various treatments involving Trichoderma species on plant shoot length, particularly the combination of 15 g Trichoderma with 25% coconut water (T2), which produced the highest mean shoot length of 15.48 cm. This value was significantly higher than that of the control treatment (T0), which recorded an average shoot length of 9.03 cm, while the treatment of 15 g Trichoderma with water (T1) resulted in a shoot length of 11.68 cm. However, the increase from T0 to T1 was not statistically significant, indicating that although Trichoderma-based treatments exert beneficial effects on plant growth, the presence of coconut water significantly enhances growth attributes when combined with this biocontrol agent.

The effectiveness of Trichoderma as a plant growth-promoting agent has been widely documented. Trichoderma harzianum has been reported to increase root biomass and stimulate lateral root formation under drought stress conditions, demonstrating its potential to mitigate stress and promote plant growth (Battaglia et al., 2024). These findings are consistent with the present study, in which the combination with organic inputs such as coconut water not only improved growth parameters but may also enhance plant physiological resilience.

Although the significant improvement observed in the T2 treatment indicates an additive effect of coconut water on the bio stimulatory activity of Trichoderma, the absence of significant differences between the control (T0) and T1 treatments suggests that Trichoderma alone does exert positive effects, but its efficacy may depend on specific environmental conditions or the presence of additional organic amendments. Coconut water is known to be rich in nutrients and plant growth hormones, which may explain the enhanced performance observed in T2, the use of organic materials as bio-amendments in combination with mycorrhizal fungi has likewise been reported to result in significant improvements in plant physiological responses and growth under stress conditions (Karim & Ismail, 2023).

The lowest mean shoot length observed in the control treatment (T0) further underscores the inherent benefits of utilizing beneficial microorganisms and organic inputs in agricultural practices. The presence of natural bio stimulants in the growing medium can enhance nutrient uptake and plant tolerance to environmental

stress, which is critical for sustainable agriculture aimed at reducing dependence on synthetic fertilizers (Jabran et al., 2024; Rashid, 2025).

Despite the marked growth improvements observed, the interactions among coconut water, Trichoderma, and plant physiological processes remain complex and warrant further investigation. For instance, metabolic products of Trichoderma, such as volatile organic compounds, have been shown to promote plant growth; however, their interactions with other organic inputs need to be further characterized to fully exploit their synergistic potential in agronomic applications (Rao et al., 2022).

3. Number of Leaves

The results of observations and analysis of variance showed that the application of Trichoderma sp. had a very significant effect. while the duration of soaking and the interaction between Trichoderma sp. and the duration of soaking did not have a significant effect on the number of leaves on pepper plant seedlings.

Table 3. Average number of leaves (strands) of pepper plant seedlings during 12 weeks after planting with Trichoderma sp. application and soaking time

Trichoderma sp.	Long soaking time/O'clock			Average
	6	9	12	
Control (T0)	1.75	2.50	3.00	2.42[b]
Trichoderma sp. 15 g + water	3.25	3.75	3.75	3.58[ab]
Trichoderma sp. 15 g + coconut water 25%	4.25	4.75	5.25	4.75[a]
Average	3.08	3.67	4.00	
LSD 5%	2.31			

Note: Numbers followed by different letters in the same row (a, b and c) and column (x, y and z) are significantly different at the LSD 5% test level.

The results of the 5% LSD test presented in Table 4 indicate that the application of Trichoderma sp. at 15 g combined with 25% coconut water (T2) resulted in the highest average number of leaves, reaching 4.75 leaves per plant. This value was significantly higher than that of the control treatment (T0), which produced an average of only 2.42 leaves per plant. However, the difference between the T2 treatment and the application of Trichoderma sp. at 15 g with water (T1), which resulted in 3.58 leaves per plant, was not statistically significant. These findings suggest that although both Trichoderma-based treatments enhanced leaf development compared to the control, the addition of coconut water tended to create more favorable conditions for leaf formation.

The beneficial effects of Trichoderma on plant growth have been widely reported. Trichoderma not only enhances plant growth but also improves plant defense mechanisms through enzyme modulation and growth-promoting activities. This synergistic effect is particularly important, as it indicates that Trichoderma sp. combined with organic inputs such as coconut water can further strengthen its positive influence on plant growth, leading to increased leaf production and overall vegetative development (Mishu et al., 2025).

Coconut water provides additional nutrients and natural plant growth hormones, such as cytokinin, which are known to stimulate cell division and cell expansion, thereby promoting shoot and leaf development. The application of organic amendments has been shown to improve plant physiological traits, including an increase in leaf number, which ultimately has a positive impact on plant productivity (Duan et al., 2024).

The lowest leaf number observed in the control treatment (T0) indicates that the absence of growth-promoting agents limits plant development. Beneficial microorganisms such as Trichoderma play an important role in enhancing plant tolerance to both biotic and abiotic stresses, which directly affects growth performance, including leaf production (Hao et al., 2022).

The relatively small and statistically non-significant difference between the T1 and T2 treatments further suggests that although Trichoderma alone is capable of stimulating plant growth, its effectiveness can be maximized when applied in combination with natural growth stimulants such as coconut water. Synergistic interactions between beneficial microorganisms and organic inputs have been reported to significantly enhance plant health and productivity (Zhi et al., 2024).

4. Shoot Stem Diameter

The results of observations and analysis of variance showed that the application of Trichoderma sp. and coconut water and the duration of soaking as well as the interaction between Trichoderma sp. and coconut water and the duration of soaking did not significantly affect the diameter of the shoot stem in pepper plant seedlings.

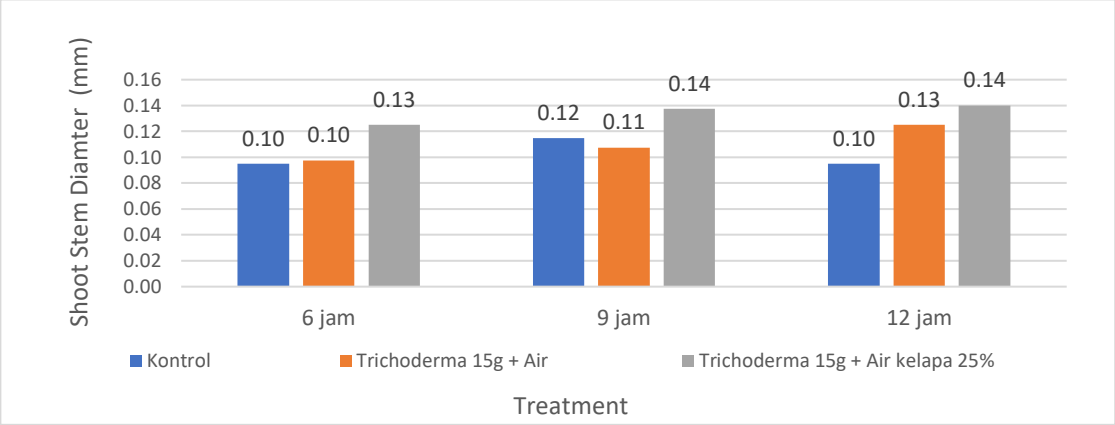

Figure 2. Average diameter of shoot stem (mm) of pepper seedling cuttings during 12 weeks after planting in response to Trichoderma sp. application and soaking time

The results presented in Figure 1 indicate that the application of Trichoderma sp. at 15 g combined with 25% coconut water, particularly with a soaking duration of 12 h (T2D3), produced the highest mean shoot stem diameter, reaching 0.14 mm. This increase contrasts with the control treatment (T0D1), which recorded the lowest diameter of 0.10 mm at a soaking duration of 6 h. The treatment of Trichoderma sp. with water (T1D1) also resulted in a diameter of 0.10 mm, as did the control treatment with a 12 h soaking duration (T0D2). These findings highlight a synergistic relationship between Trichoderma and coconut water, reinforcing the notion that their combination provides superior growth benefits.

The increase in shoot stem diameter can be attributed to the presence of bioactive compounds in coconut water. Coconut water is rich in plant growth hormones such as cytokinin, which play a crucial role in stimulating cell division and tissue growth. Scientific evidence indicates that cytokinin can significantly stimulate shoot and root growth, resulting in thicker and healthier stems (Setyowati et al., 2023). In addition to hormonal stimulation, the application of Trichoderma sp. has been reported to enhance nutrient uptake, improve soil structure, and increase soil microbial activity, which collectively support plant growth and development (Kredics et al., 2024). The interaction between Trichoderma inoculation and growth-promoting factors in coconut water is likely to be synergistic, leading to greater shoot stem diameters.

Furthermore, increased stem diameter may reflect improved plant health and structural integrity, which are essential for supporting leaf development and overall plant vigor during critical growth stages. As reported by Wang et al. (2025), plants treated with beneficial microorganisms such as Trichoderma exhibit significant improvements across various growth parameters compared to untreated plants, underscoring the effectiveness of these biocontrol agents. Moreover, the greater stem diameter observed under the T2D3 treatment suggests that longer soaking durations allow more effective root colonization by Trichoderma, thereby facilitating greater biomass accumulation in the aerial parts of the plant (Nurbailis et al., 2025).

In contrast, the results obtained from the control treatments (T0D1 and T0D2) indicate that, in the absence of biocontrol agents and organic amendments, plant growth remains limited. As reported by Marwan et al. (2023), untreated seeds or seedlings are often more susceptible to disease and experience suboptimal growth conditions, which may explain the lower stem diameter values observed in the control treatments.

Several studies have shown that the effectiveness of Trichoderma as a biocontrol agent lies not only in its ability to promote plant growth but also in its capacity to suppress soil-borne pathogens, thereby reducing competitive stress on plants (Dave et al., 2024). Therefore, the significant increase in shoot stem diameter observed under the T2D3 treatment is consistent with broader findings in plant pathology, suggesting that microbial inoculants can contribute to healthier overall plant growth.

5. Root volume

The results of observations and analysis of variance showed that the application of Trichoderma sp. and the duration of immersion had a very significant effect. but the interaction between Trichoderma sp. and the duration of immersion had no significant effect on the root volume of cuttings in pepper plant seedlings.

Table 4. Average root volume (ml) of pepper plant seedlings during 12 weeks after planting with Trichoderma sp. application and soaking time

Trichoderma sp.	Long soaking time/O'clock			Average
	6	9	12	
Control (T0)	2.75	3.75	4.00	3.50^{b}
Trichoderma sp. 15 g + water	3.50	5.00	5.50	4.67^{ab}
Trichoderma sp. 15 g + coconut water 25%	4.50	6.00	6.50	5.67^{a}
Average	3.58^{y}	4.92^{xy}	5.33^{x}	
LSD 5%	1.50			

Note: Numbers followed by different letters in the same row (a, b and c) and column (x, y and z) are significantly different at the LSD 5% test level.

The results of the LSD 5% test in Table 4 show that the application of 15 g of Trichoderma sp. + 25% coconut water (T2) produced the best root volume of 5.67 ml. significantly different from the control treatment (T0) with a root volume of 3.50 ml. but not significantly different from the 15 g of Trichoderma sp. + water treatment (T1) with a root volume of 4.67 ml. The lowest average root volume was obtained in the control treatment (T0). at 3.50 ml. and not significantly different from the 15 g of Trichoderma sp. + water treatment (T1).

A 12-hour soaking period (D3) produced the best root volume of 5.33 ml. significantly different from the 6-hour soaking treatment (D1) with a root volume of 3.58 ml. but not significantly different from the 9-hour soaking treatment (D2) with a root volume of 4.92 ml. The lowest average root volume was obtained in the 6-hour immersion treatment. namely 3.58 ml and was not significantly different from the 9-hour immersion treatment (D2).

The results of the HSD 5% test indicate that the application of Trichoderma sp. combined with 25% coconut water (T2) resulted in a significant increase in root volume, reaching 5.67 mL. This value was substantially higher than that of the control treatment (T0), which recorded a root volume of only 3.50 mL. In contrast, the treatment with Trichoderma sp. and water (T1) produced a root volume of 4.67 mL, which, although higher than the control, was not statistically different from the T2 treatment. These results confirm the synergistic potential of combining biocontrol agents such as Trichoderma with organic inputs such as coconut water to promote root growth.

The growth-promoting capacity of Trichoderma has been widely reported in the literature. This microorganism is known to enhance plant growth by improving nutrient uptake, increasing root biomass, and strengthening plant resistance to pathogen attack (Xue et al., 2021; Srivastava et al., 2025). Several studies have also demonstrated that Trichoderma activity promotes the establishment of beneficial soil microbial communities, which in turn stimulate root development and enhance overall plant vigor (Marwan et al., 2023). In the present study, the application of coconut water, which is rich in cytokinin and other growth hormones, likely contributed to the observed increase in root volume (Puspita, 2025).

The trend indicating that a 12 h soaking duration (D3) resulted in the highest root volume (5.33 mL) compared with the 6 h (D1) and 9 h (D2) soaking treatments highlights the importance of soaking duration in maximizing treatment benefits. The 6 h soaking period produced the lowest root volume (3.58 mL) and was not significantly different from the 9 h treatment. This suggests that while shorter soaking durations already provide benefits, prolonged exposure to the combined treatments may optimize the absorption of growth-promoting compounds from coconut water and facilitate more effective root colonization by Trichoderma (Awla, 2025).

Previous studies support the notion that soaking seeds or planting materials in growth-promoting solutions can enhance plant physiological responses. The duration of exposure to bioinoculants has been

shown to significantly influence nutrient uptake and root growth across various crops. This is consistent with the present findings, indicating that an optimal interaction between soaking duration and biotic treatments plays a crucial role in achieving maximum root development.

Furthermore, the low mean root volume observed in the control treatment (T0) underscores the critical role of integrated biotechnological approaches such as the use of microbial inoculants and natural growth stimulants in supporting successful plant establishment and early growth. Previous studies have shown that untreated plants often exhibit reduced vigor due to suboptimal nutrient availability and increased susceptibility to pests and diseases (Rao et al., 2022).

The findings of this study demonstrate the superiority of applying Trichoderma sp. in combination with coconut water for effectively enhancing root volume and suggest that this practice has the potential to contribute significantly to improved agricultural productivity. Future research is recommended to explore the optimal ratios of coconut water to Trichoderma application and to elucidate the specific physiological mechanisms underlying the observed enhancement in root growth.

6. Presentation of success

The results of observations and analysis of variance showed that the application of Trichoderma sp. and the soaking time had a very significant effect. but the interaction between Trichoderma sp. and soaking time did not have a significant effect on the percentage of successful cuttings in pepper plant seedlings.

Table 5. Average root volume (ml) of pepper plant seedlings during 12 weeks after planting with Trichoderma sp. application and soaking time

Trichoderma sp.	Long soaking time/O'clock			Average
	6	9	12	
Control (T0)	37.50	56.25	68.75	54.17^{b}
Trichoderma sp. 15 g + water	50.00	68.75	93.75	70.83^{ab}
Trichoderma sp. 15 g + coconut water 25%	75.00	87.50	100.00	87.50^{a}
Average	54.17^{x}	70.83^{xy}	87.50^{x}	
LSD 5%	32.62			

Note: Numbers followed by different letters in the same row (a, b and c) and column (x, y and z) are significantly different at the LSD 5% test level.

The results of the LSD 5% test in Table 6 show that the application of Trichoderma sp. 15 g + 25% coconut water (T2) provided the best percentage of cutting success (%) of 87.50%. significantly different from the control treatment (T0) with a percentage of cutting success of 54.17%. but not significantly different from the treatment of Trichoderma sp. 15 g + water (T1) with a percentage of cutting success of 70.83%. The lowest average percentage of cutting success was obtained in the control treatment (T0). namely 54.2%. and not significantly different from the treatment of Trichoderma sp. 15 g + water (T1).

A 12-hour soaking period (D3) provided the best percentage of cutting success of 87.5%. significantly different from the 6-hour soaking treatment (D1) with a percentage of cutting success of 54.17%. but not significantly different from the 9-hour soaking treatment (D2) with a percentage of cutting success of 70.83%. The lowest average percentage of successful cuttings was obtained in the 6-hour immersion treatment (D1). namely 54.17% and was not significantly different from the 9-hour immersion treatment (D2).

The results of the 5% LSD test indicate that the application of Trichoderma sp. at 15 g combined with 25% coconut water (T2) produced the highest cutting success rate, reaching 87.50%. This value represents a significant improvement compared with the control treatment (T0), which achieved a cutting success rate of only 54.17%. The results further show that the treatment of Trichoderma sp. with water (T1) resulted in an intermediate cutting success rate of 70.83%, although this was not statistically different from the T2 treatment. These findings confirm the effectiveness of combining coconut water with Trichoderma in enhancing cutting establishment success.

The effectiveness of Trichoderma as a biocontrol agent has been widely reported in the literature. Trichoderma species are well known for their ability to promote plant growth and improve root development through the production of various secondary metabolites and the stimulation of beneficial microbial interactions in the rhizosphere (Puspita, 2025). In particular, the addition of coconut water supplies natural phytohormones

such as cytokinin, which play a crucial role in stimulating root proliferation and enhancing overall plant vigor (Rao et al., 2022). The observed increase in cutting success is likely attributable to the synergistic effects of these compounds, which facilitate root formation and successful establishment of cuttings under favorable growth conditions.

The results show that a soaking duration of 12 h (D3) yielded a cutting success rate of 87.50%, which was markedly higher than that observed with the 6 h soaking treatment (D1) at 54.17%. Soaking duration appears to significantly influence the response of cuttings to the treatments. Previous studies have demonstrated that longer exposure to growth-promoting solutions such as coconut water can enhance the uptake of nutrients and growth regulators required for successful rooting (Setyowati et al., 2023). This suggests that sufficient soaking time not only improves the absorption of beneficial agents but also allows Trichoderma to colonize cutting tissues more effectively, thereby stimulating root initiation and supporting overall plant health (Xue et al., 2021).

Interestingly, the 9 h soaking treatment (D2) resulted in a cutting success rate of 70.83%, which was not significantly different from the T1 treatment, indicating a plateau effect in which prolonged soaking beyond a certain threshold does not yield further significant improvements. This finding is consistent with reports that optimal soaking duration may vary depending on plant species and environmental conditions (Bhuiyan et al., 2021). The lower success rates observed under shorter soaking durations suggest that insufficient exposure to growth-promoting agents may limit root emergence and subsequent growth.

Overall, these results provide strong support for the integration of biological agents such as Trichoderma with organic inputs like coconut water in improving the success of cutting propagation techniques. The enhanced cutting success observed in this study is consistent with previous reports demonstrating that the use of bioinoculants can significantly improve growth parameters across various horticultural applications (Abdel-Rahman et al., 2023; Mulyani et al., 2024).

CONCLUSIONS

Application of 15 g of Trichoderma sp. + 25% coconut water produced the best results. with a shoot emergence time of 35.9 days after planting. a shoot length of 15.5 cm. a leaf count of 4.8. a root volume of 5.67 ml. and a cutting success rate of 87.5%. A 12-hour soaking period produced the best results. with a shoot emergence time of 32.7 days after planting. a root volume of 5.33 ml. and a cutting success rate of 87.5%.

The interaction between Trichoderma sp. application and soaking period was not statistically significant. but showed the highest average value in the 12-hour soaking period with a shoot emergence time of 29.4 days after planting. a shoot length of 17.1 cm. a leaf count of 5.3. a stem diameter of 0.14 mm. and a cutting success rate of 100%.

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