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EFFECTS OF DOSAGE AND APPLICATION FREQUENCY OF FOLIAR-APPLIED MATURE COCONUT WATER ON COCOA (*Theobroma cacao* L.) SEEDLING GROWTH

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ABSTRACT:

Indonesia's cocoa production has experienced instability in recent years, highlighting the need to improve productivity through intensification and extensification strategies. The success of these approaches is highly dependent on the availability of high-quality seedlings. Therefore, the utilization of coconut water as a natural plant growth regulator and supplementary nutrient source has potential to enhance cocoa seedling growth. This study aimed to evaluate the effects of different doses and application frequencies of mature coconut water applied as a foliar spray on cocoa seedling growth and to determine the most effective treatment combination. The experiment was conducted from December 2025 to May 2026 at the Ciparanje Experimental Field, Faculty of Agriculture, Universitas Padjadjaran, Jatinangor, located at an altitude of approximately 752 m above sea level. A Randomized Block Design (RBD) consisting of ten treatments and three replications was employed. Treatments comprised combinations of mature coconut water doses of 10, 15, and 20 mL plant^{-1} applied at intervals of 7, 14, and 21 days, while a 0.2% urea treatment served as the control. Observed variables included plant height, stem diameter, and leaf number. The results showed that foliar application of mature coconut water significantly increased cocoa seedling stem diameter at 6–10 weeks after treatment. In addition, variations in coconut water dose and application frequency were able to support plant height and leaf production with effectiveness comparable to that of the inorganic fertilizer treatment (urea). For stem diameter, the application of 10, 15, and 20 mL plant^{-1} resulted in significantly greater values than the control treatment. Among the tested application intervals, the 21-day interval was found to be the most effective.

Key words: Intensification, Natural plant growth regulator, Productivity, Stem diameter

INTRODUCTION

The cacao plant (*Theobroma cacao* L.) is widely cultivated in Indonesia due to high market demand and stable selling prices. Indonesian cocoa is not only processed into food products but is also in demand in the cosmetics and pharmaceutical industries (Pusat Data dan Sistem Informasi Pertanian, 2022). According to the latest data from the International Cocoa Organization or ICCO (2025) for the 2022/2023 period, Indonesia’s cocoa bean production ranked only 7th globally with a total of 160,000 metric tons, behind Côte d’Ivoire (2,241,000 metric tons), Ghana (654,000 metric tons), Ecuador (454,000 metric tons), Nigeria (315,000 metric tons), Cameroon (270,000 metric tons), and Brazil (220,000 metric tons). This ranking reflects a significant downward trend; Indonesia, which was still ranked 4th globally in the 2016/2017 period, has remained stagnant at 7th place since 2017.

The decline in cocoa bean production in Indonesia over the past eight years has been driven by two main issues: a reduction in plantation area and low productivity levels (Direktorat Statistik Tanaman Pangan Hortikultur dan Perkebunan, 2024; Norfahmi *et al*., 2019). Intensification and extensification are considered the most effective strategies for maximizing the potential of cocoa land (Nadila & Kurniati, 2025). The success of these two strategies heavily depends on the proper preparation of seedlings before transplanting. This is because good nursery management produces high-quality plants with high productivity and supports agricultural sustainability (Boruah *et al*., 2024).

Good cocoa seedlings can be identified by optimal plant height, a large stem diameter, and well-developed root systems. This is supported by Ishida *et al*. (2023) who state that cocoa seedlings with high photosynthetic activity and good biomass growth also reflect high plant vigor, making them better able to adapt after being transplanted to the field.

The cocoa seedling phase often faces challenges such as relatively slow growth due to environmental constraints, which affect the plant's physiological processes (Ishida *et al*., 2023). These conditions are often accompanied by small stem size and low plant vigor, reflecting suboptimal vegetative growth (Baligar *et al*., 2021). Furthermore, the development of the root system in cocoa seedlings is often suboptimal, even though roots play a crucial role in the absorption of water and nutrients to support plant growth (Lahive *et al*., 2019).

Various efforts can be made to enhance the growth of cocoa seedlings during the nursery phase, one of which is through the application of plant growth regulators (PGRs) that can stimulate plant physiological processes. Coconut water (*Cocos nucifera* L.) is a highly promising organic waste material for this purpose because it has a biochemical composition rich in nutrients and bioactive compounds (Shi *et al*., 2025). This natural material contains various plant growth hormones such as IAA (0.0039%), cytokinin (0.0017%), zeatin (0.0019%), kinetin (0.0053%), and gibberellin (GA3) (0.0018%) (Rosniawaty *et al*., 2018). In addition to hormones, based on the results of an analysis by Gaddamwar and Water (2013), coconut water contains various essential minerals such as K (247 mg/100 mL), P (6.3 mg/100 mL), Na (48 mg/100 mL), Ca (40 mg/100 mL), Mg (15 mg/100 mL), Cu (26 mg/100 mL), and Fe (79 mg/100 mL). The synergy between these hormonal compounds and nutrients demonstrates coconut water's potential as an effective natural growth regulator for enhancing plant physiological performance and growth.

This plant growth regulator (PGR) application strategy is carried out via the leaves (foliar application) to overcome nutrient absorption limitations caused by the root system being confined within polybags. The foliar method was chosen because it allows for more responsive absorption of the active ingredient through the stomata and cuticular pores (Ishfaq *et al*., 2022). Through the spraying mechanism, the coconut water solution forms a thin layer on the leaf surface, facilitating the diffusion of ions and sugars into the cytoplasm (Pooja & Ameena, 2023). Additionally, foliar application is considered more efficient because it reduces the risk of losing active compounds due to leaching or fixation in the soil (Ulfa *et al*., 2022).

According to technical guidelines, foliar nutrient application should be performed at least once every three weeks to ensure optimal absorption (Heirloom Cacao Preservation, 2024). However, past research shows that plants react differently to spraying frequency. Rosniawaty *et al.* (2021) reported that changing the spraying interval (every 3, 7, 14, or 21 days) resulted in differences in the growth of cacao seedlings. This indicates that application frequency is a key factor in determining the extent to which the natural hormones in coconut water can be absorbed and utilized by the plants. A more recent study from by Rosniawaty *et al*. (2024) which tested application intervals of every 3, 7, 14, and 21 days, found that applying coconut water every 21 days to Arabica coffee seedlings was actually the most effective in promoting height growth and the number of leaves. Therefore, variations in application frequency are an important factor to be further studied to determine the most efficient application interval for supporting cocoa seedling growth.

In addition to frequency, variations in the application dose of the solution are also important factors that determine the effectiveness of the plants' growth response. Coconut water is a liquid medium containing nutrients similar to liquid organic fertilizer. Research findings on liquid organic fertilizer (POC) indicate a positive effect on plants. A study conducted by Gunawan *et al*. (2024) showed that applying POC at doses of 10 mL plant^{-1}, 15 mL plant^{-1}, and 20 mL plant^{-1} via direct application to the plants provided insight into the optimal dose range for supporting the growth of cocoa seedlings. Based on these findings, the optimal dose was determined to be 20 mL plant^{-1}. Meanwhile, according to a study by Rosniawaty *et al*. (2024) the foliar application of coconut water at a dose of 100 mL mL plant^{-1}, applied six times, had the most consistent effect on the height, chlorophyll index, and root volume of cocoa seedlings. This dose can serve as a reference in the present study.

Although various studies have examined the effects of coconut water dosage and application frequency, information regarding the combination of these two factors and their ability to produce growth comparable to inorganic fertilizers during the seedling phase remains limited.

MATERIAL AND METHODS

The materials used to support this study were cocoa beans from cocoa pods sourced from farmers in Sekarwangi Village, Buahdua Subdistrict, Sumedang Regency, West Java. The growing medium consisted of Inceptisol topsoil and cattle manure, water, urea fertilizer, the fungicide Dithane M-45 (active ingredient: mancozeb), and mature coconut water from local coconut plantations. The tools used included a hoe, 15 × 25 cm polybags, a vernier calliper, a hand sprayer, writing utensils, documentation tools, laboratory equipment, and 75% shade net.

This study was conducted at the Ciparanje Experimental Farm of the Faculty of Agriculture, Padjadjaran University, Jatinangor, Sumedang Regency, West Java, at an elevation of approximately 752 m above sea level, from December 2025 to May 2026. This study employed a Randomized Block Design (RBD) experimental method consisting of ten treatments, three replicates, and each treatment comprising three plants in a triplicate arrangement, thus requiring 90 cocoa seedlings. The treatments tested were as follows:
A = 10 mL of coconut water plant^{-1}, once every 7 days
B = 10 mL of coconut water plant^{-1}, once every 14 days
C = 10 mL of coconut water plant^{-1}, once every 21 days
D = 15 mL of coconut water plant^{-1}, once every 7 days
E = 15 mL of coconut water plant^{-1}, once every 14 days
F = 15 mL of coconut water plant^{-1}, once every 21 days
G = 20 mL of coconut water plant^{-1}, once every 7 days
H = 20 mL of coconut water plant^{-1}, once every 14 days
I = 20 mL of coconut water plant^{-1}, once every 21 days
J = 50 mL of 0.2% Urea solution plant^{-1} applied directly to the soil, once every 14 days.

Plant height was measured with a ruler in centimetres (cm). Plants were measured from the base of the stem to the growing point. Stem diameter was measured at the base of the stem, 3 cm above the soil surface, using a vernier calliper in millimetres. The number of leaves was determined by counting the number of fully expanded leaves. Observations were conducted every two weeks, beginning the week after treatment (0 WAT), 2 WAT, 4 WAT, 6 WAT, 8 WAT, 10 WAT, 12 WAT, 14 WAT, and 16 WAT. Experimental data analysis was performed using the SmartstatXL

RESULT AND DISCUSSION

Plant height (cm)

Based on Table 1, it is evident that foliar application of coconut water has not yet shown a significant effect on the height growth of cocoa seedlings at 0–16 WAT. However, overall, seedling height continued to increase from a range of 16.97–18.92 cm at the start of the observation to 34.17–40.17 cm at 16 WAT, where this growth remains comparable to that of the control treatment.

Tabel 1. Effects of Dose and Application Frequency of Foliar-Applied Mature Coconut Water on the Height Growth of Cocoa (*Theobroma cacao* L.) Seedlings

T	0 WAT	2 WAT	4 WAT	6 WAT	8 WAT	10 WAT	12 WAT	14 WAT	16 WAT
A	16.97	17.46	18.99	19.62	21.20	24.19	26.69	30.72	34.17
B	18.51	18.91	19.91	21.37	23.78	26.20	30.72	35.06	38.29
C	17.30	18.00	19.17	20.32	22.72	25.68	30.17	33.72	38.35
D	17.59	18.03	19.31	20.32	21.33	25.23	27.45	31.33	34.39
E	17.75	18.31	19.20	20.07	22.19	25.19	27.72	31.11	35.38
F	18.92	19.30	20.33	21.07	22.17	24.37	29.63	32.67	37.17
G	17.77	18.34	19.82	20.83	23.33	25.27	29.69	33.17	37.93
H	18.57	19.24	20.40	21.16	24.01	27.42	31.17	36.39	40.17
I	18.14	18.70	20.11	20.78	22.37	24.47	27.39	31.00	35.63
J	17.41	17.91	19.06	19.61	22.13	26.40	30.38	34.83	39.93

Notes:
1) WAT: Weeks After Treatment
2) T: Treatment; A: 10 mL/7 days; B: 10 mL/14 days; C: 10 mL/21 days; D: 15 mL/7 days; E: 15 mL/14 days; F: 15 mL/21 days; G: 20 mL/7 days; H: 20 mL/14 days; I: 20 mL/21 days; J: control

In this experiment, although the application of coconut water did not result in a significant difference in plant height, all treatments still showed a consistent increase in height during the observation period. These results indicate that the nutrient requirements for supporting the vegetative growth of the seedlings were still fulfilled adequately across all treatments.

Furthermore, the relatively uniform response in plant height across treatments also indicates that coconut water applied via foliar application plays a greater role in maintaining the plants' physiological condition rather than stimulating excessive stem elongation. Therefore, the results of this study indicate that the application of coconut water is capable of supporting the vegetative growth of cocoa seedlings until they reach a height equivalent to that of the control treatment, although it has not yet been able to produce a statistically significant increase in plant height. In fact, based on the Indonesia's Good Agriculture Practices/GAP on Cocoa (2014) which sets the minimum height for transplant-ready seedlings at 40 cm, treatment H was the first group to meet this requirement.

Stem Diameter (mm)

Based on Table 2, it was found that the application of coconut water had a significant effect on the growth of the stem diameter of cocoa seedlings at 6–10 WAT.

Tabel 2. Effects of Dose and Application Frequency of Foliar-Applied Mature Coconut Water on the Stem Diameter Growth of Cocoa (*Theobroma cacao* L.) Seedlings

T	0 WAT	2 WAT	4 WAT	6 WAT	8 WAT	10 WAT	12 WAT	14 WAT	16 WAT
A	3.21	3.53	4.09	4.54 abc	4.63 cd	4.87 bcd	5.86	6.54	7.21
B	3.20	3.74	4.14	4.50 abc	5.07 ab	4.79 cd	5.62	6.36	7.64
C	3.07	3.50	4.02	4.36 c	4.73 c	5.15 abc	6.04	6.47	7.78
D	3.09	3.71	4.37	4.73 ab	5.14 a	5.17 abc	6.10	6.19	7.69
E	3.21	3.58	4.05	4.44 bc	4.66 cd	5.18 abc	6.06	6.48	7.54
F	3.09	3.58	4.04	4.41 c	4.84 bc	5.20 abc	5.95	6.42	7.61
G	3.28	3.49	4.13	4.62 abc	4.82 bc	5.27 ab	6.08	6.60	7.82
H	3.24	3.65	4.21	4.74 a	5.16 a	5.28 ab	6.22	6.77	7.79
I	3.16	3.52	4.17	4.56 abc	5.22 a	5.49 a	6.17	6.76	7.60
J	3.01	3.30	3.81	4.08 d	4.43 d	4.59 d	5.71	6.24	7.25

Notes:

1) WAT: Weeks After Treatment
2) T: Treatment; A: 10 mL/7 days; B: 10 mL/14 days; C: 10 mL/21 days; D: 15 mL/7 days; E: 15 mL/14 days; F: 15 mL/21 days; G: 20 mL/7 days; H: 20 mL/14 days; I: 20 mL/21 days; J: control

At 6 WAT, treatment H (20 mL/14 days) had the largest diameter compared to treatments C, E, F, and J, but was not significantly different from treatments A, B, D, G, and J. Furthermore, at 8 WAT, treatments D (15 mL/7 days), H (20 mL/14 days), and I (20 mL/21 days) had larger stem diameters than treatments A, C, E, F, and J, but were not significantly different from treatment B. Meanwhile, at 10 WAT, treatment I (20 mL/21 days) had the highest plant diameter compared to treatments C, D, E, F, G, and H, but showed no significant difference from treatments A, B, and J. During this period, it was also observed that the control treatment tended to produce the lowest stem diameter compared to the other treatments.

Stem diameter development is closely related to cell division and enlargement in the cambium tissue. These activities can be stimulated by the hormones cytokinin, auxin, and gibberellin, and supported by the availability of potassium. This is consistent with the fact that coconut water contains all three of these compounds, as reported by Rosniawaty *et al*. (2018). Meanwhile, urea in the control treatment could not stimulate these activities due to its specific role in providing nitrogen.

The synergy between cytokinins in stimulating meristem cell division, auxins in vascular tissue differentiation, and gibberellins in supporting cell enlargement plays a crucial role in optimizing plant stem growth (Kieber & Schaller, 2018; Nufus, 2025). The combined hormonal activity of these three substances is believed to be the reason why the coconut water treatment resulted in a larger stem diameter than the control.

In addition to its growth hormone content, the potassium in coconut water may also help support stem diameter growth by regulating enzyme activity and the translocation of plant photosynthetic products. This aligns with the statement by Wang *et al*. (2013) that potassium plays a crucial role in regulating plant metabolism, the translocation of photosynthates, and plant tissue formation. The availability of potassium from coconut water may help enhance vegetative plant growth, including stem development.

The frequency of foliar applications is also thought to influence the effectiveness of leaf uptake of bioactive compounds from coconut water; as shown in this experiment, applications every 7 days were no more effective than every 14 or 21 days. Too frequent application intervals do not necessarily enhance plant growth responses because leaves have limited absorption capacity within a given period (Fernández & Brown. 2013). After the solution is absorbed through the stomata and cuticle, plants require time to translocate and utilize these compounds in metabolic processes and tissue growth. As explained by oleh Otto *et al*. (2021) compounds from foliar applications must pass through the epidermal tissue, apoplast, and symplast before being utilized by the plant; thus, the absorption and translocation processes require a certain amount of time. If applications are made too frequently, the plant will require more time to process the absorbed compounds.

The lack of a significant effect at 12–16 WAT is likely due to the fact that as plant size increases, the demand for hormones to support cambium activity continues to rise, while the dose of coconut water remains constant. Consequently, the nutrient contribution becomes too small relative to the plant's total needs. This indicates that while the stimulatory effect of coconut water is indeed present, its scope is limited to the early to mid-seedling stages only.

Number of leaves (sheets)

Based on Table 3, it was found that there was no significant effect of coconut water application on the number of leaves in cocoa seedlings from 0–16 WAT. All treatments showed a similar increase in the number of leaves, ranging from 3.67–4.11 leaves at 0 WAT to 15.89–18.22 leaves at 16 WAT.

Tabel 3. Effects of Dose and Application Frequency of Foliar-Applied Mature Coconut Water on the Number of Leaves Growth of Cocoa (*Theobroma cacao* L.) Seedlings

T	0 WAT	2 WAT	4 WAT	6 WAT	8 WAT	10 WAT	12 WAT	14 WAT	16 WAT
A	3.67	3.67	6.22	6.45	9.55	10.22	14.00	14.34	15.89
B	3.78	4.22	6.67	7.44	10.22	11.55	13.89	15.56	16.78
C	3.67	4.22	6.55	7.11	9.45	10.44	13.11	14.55	16.67
D	3.89	4.00	7.11	7.22	9.67	10.66	12.67	14.44	16.33
E	4.11	4.22	6.89	7.11	9.89	10.78	13.00	14.67	16.67
F	4.00	4.33	6.55	7.73	9.33	9.78	13.22	14.00	17.67
G	3.67	3.78	6.78	7.22	9.56	10.45	13.45	14.56	17.56
H	4.11	4.11	7.44	8.00	10.89	10.89	13.89	16.22	18.22
I	3.78	4.00	6.33	6.78	9.44	10.44	12.78	15.34	16.78
J	3.67	4.00	6.11	6.89	9.44	11.00	13.33	15.33	17.45

Notes:
1) WAT: Weeks After Treatment
2) T: Treatment; A: 10 mL/7 days; B: 10 mL/14 days; C: 10 mL/21 days; D: 15 mL/7 days; E: 15 mL/14 days; F: 15 mL/21 days; G: 20 mL/7 days; H: 20 mL/14 days; I: 20 mL/21 days; J: control

The absence of a significant effect may be related to the periodic leaf growth patterns in cocoa plants. As described by Almeida and Valle (2008) the flushing period or cycle in cocoa plants is characterized by synchronous leaf growth controlled by the plant's internal physiological balance. This cycle is regulated by the balance of endogenous hormones, such as ABA, auxin, and cytokinin, and involves carbohydrates (Almeida & Valle, 2008). Because this cycle is endogenous, the application of exogenous plant growth regulators via foliar application at a dose of used in this study was unable to alter this natural growth pattern. This finding is also consistent with the report by Wahyono *et al*. (2020) who also found that various concentrations of coconut water (0, 25, 50, 75%) had no significant effect on the number of leaves on cocoa seedlings.

CONCLUSION

The application of mature coconut water at various doses and frequencies significantly increased the stem diameter of cocoa seedlings at 6–10 WAT. In addition, the application of mature coconut water at varying doses and frequencies also supported the growth of cocoa seedling's height and number of leaves with effectiveness comparable to that of inorganic fertilizer (urea) treatments. Regarding stem diameter, the application of 10, 15, and 20 mL doses yielded significantly better results than the control. Among these treatments, an application frequency of once every 21 days proved to be the most effective interval.

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