Vegetative growth of red ginger (Z*ingiber officinale rubrum*) in response to young coconut water concentration and soaking duration

Amalia Rahma Fadillah[1], *Astuti* Kurnianingsih[1*]

[1]Agronomy Study Program, Faculty of Agriculture, Universitas Sriwijaya, Indonesia

Abstract. Red ginger (*Zingiber officinale* var. *rubrum*) is a high-value medicinal plant widely used in the pharmaceutical and herbal industries. However, its cultivation is often constrained by slow and non-uniform early growth resulting from variable rhizome quality and suboptimal pre-planting treatments. Young coconut water contains bioactive compounds that may promote germination and vegetative development; however, its optimal concentration and soaking duration for red ginger propagation remain unclear. This study aimed to evaluate the effects of young coconut water concentration and soaking duration on the early vegetative growth of red ginger. The experiment was conducted using a factorial randomized block design (5 × 2) with three replications. The first factor consisted of young coconut water concentrations (0%, 25%, 50%, 75%, and 100%), while the second factor was soaking duration (12 and 24 h). Observed parameters included sprouting time, number of shoots, leaf number, and biomass accumulation. Data were analyzed using analysis of variance followed by Duncan's Multiple Range Test at the 5% significance level. The results showed that young coconut water significantly affected several early growth parameters of red ginger. A 50% concentration provided the best overall response, as indicated by higher leaf number and biomass accumulation, whereas a 75% concentration promoted faster shoot emergence and a greater number of shoots. A soaking duration of 12 h was more effective than 24 h in improving growth performance. The interaction between a 50% concentration and a 12-h soaking duration resulted in the most favorable overall growth response. These findings indicate that young coconut water has potential as a natural growth-promoting substance for enhancing the early growth of red ginger.

Keywords: biomass accumulation; growth-promoting substance; rhizome soaking; sprouting time

1. Introduction

Ginger (*Zingiber officinale Rosc*.) is a perennial plant with high economic value and is widely exported to various countries. One of the ginger varieties extensively cultivated and utilized in Indonesia is red ginger (*Zingiber officinale* var. *rubrum*) [1]. According to the Statistics Indonesia [2], Indonesian ginger production in 2024 reached 190,257 tons, representing a decline compared with the 198,873 tons recorded in 2023. This decrease indicates that efforts to improve ginger production continue to face several constraints, particularly those related to cultivation practices and the availability of high-quality planting materials. Wardana et al. [3] reported that one of the major limitations in red ginger cultivation occurs during the seedling stage, especially due to the dormancy period of rhizomes after harvest. This dormancy prolongs the cultivation period and results in slow initial plant growth.

One approach to overcome this problem is the application of pre-planting treatments using plant growth regulators (PGRs). Coconut water is one of the natural materials that can be utilized as a source of growth-promoting substances. Rosniawaty et al. [4] stated that young coconut water (*Cocos nucifera* L.) contains nutrients and various bioactive compounds that support plant physiological processes. This is supported by the study of Ernawati et al. [5] which demonstrated that the indole-3-acetic acid (IAA) present in young coconut water can stimulate the growth of red chili plants. These compounds have been reported to play important roles in cell division and differentiation, which may contribute to shoot formation and early plant growth.

Limbongan and Tambing [6] reported that the application of natural plant growth regulators derived from coconut water at a concentration of 75%, combined with a 12-hour soaking period of red ginger rhizomes, produced the best growth response compared with concentrations of 0%, 25%, 50%, and 100%. In contrast, Rokhmah [7] found that young coconut water concentrations of 0%, 25%, 50%, and 75% did not significantly affect most growth variables, except for leaf area and fresh plant weight, with the best results observed at the 50% concentration level. These inconsistent findings indicate that the effects of young coconut water on red ginger growth remain variable and are influenced by the treatment conditions applied.

The duration of rhizome soaking plays an important role in determining the effectiveness of bioactive compound uptake from young coconut water into rhizome tissues. Therefore, selecting an appropriate concentration of young coconut water and soaking

*Corresponding author: astutikurnianingsih@fp.unsri.ac.id

duration is essential to support the early growth of red ginger plants.

2. Materials and Methods

The equipment used in this study included: 1) writing materials, 2) a watering can, 3) plastic cups, 4) measuring cylinders, 5) a smartphone camera, 6) plastic folders, 7) an oven, 8) a ruler, 9) ImageJ software, 10) a SPAD meter (Soil Plant Analysis Development), 11) markers, 12) a stapler, and 13) a digital balance.

The materials used in this experiment consisted of: 1) water, 2) young coconut water, 3) rice husk charcoal, 4) polybags, 5) cattle manure, 6) NPK 15–15–15 fertilizer, 7) red ginger rhizomes, and 8) soil.

The experiment was arranged in a factorial Randomized Complete Block Design (RCBD) with a 5 × 2 treatment structure and three replications, resulting in 10 treatment combinations and 30 experimental units. The first factor was the concentration of young coconut water (0%, 25%, 50%, 75%, and 100%), while the second factor was the soaking duration (12 h and 24 h). The data were analyzed using analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Red ginger rhizomes (cultivar Jahira 2) were obtained from the Berkah Alam medicinal plant seed producer group, Sukabumi, West Java, Indonesia. Rhizomes were cleaned and selected for uniformity, with an average length of approximately 5 cm and a weight of approximately 20 g. Young coconut water was obtained from green tall coconuts at a maturity stage of approximately 5–6 months, sourced from the same supplier in Palembang, South Sumatra, Indonesia. The coconuts were selected based on uniform characteristics, including large round fruits, clear coconut water, and soft gelatinous endosperm. The planting medium consisted of soil, rice husk charcoal, and cattle manure mixed at a 1:1:1 ratio (w/w), with 500 g of medium placed in each polybag. Rhizomes were planted vertically at a depth of approximately 2 cm with the bud facing upward. Plant maintenance included watering twice daily, manual weed control, and application of NPK 15–15–15 fertilizer at a rate of 0.20 g plant^{-1} at 6 weeks after planting.

3. Results

The analysis of variance revealed that the interaction between young coconut water concentration and soaking duration significantly influenced several early growth parameters of red ginger. The interaction effect was highly significant for time to shoot emergence, while number of shoots, root fresh weight, and root dry weight showed significant interaction effects. In contrast, number of leaves, plant height, leaf greenness, leaf area, root length, shoot fresh weight, shoot dry weight, shoot-to-root ratio, rhizome fresh weight, and rhizome dry weight were not significantly affected by the interaction. The main effect of young coconut water concentration significantly influenced most biomass-related variables, whereas soaking duration significantly affected root fresh weight, root dry weight, and rhizome fresh weight (Table 1).

Time to shoot emergence varied significantly among treatments, indicating differences in early sprouting response. The shortest emergence time was observed in A3P1 (75% young coconut water concentration with 12 h soaking duration), which recorded 8.44 days after planting. This was followed by A2P1, whereas A2P2 and A3P2 also produced relatively earlier shoot emergence than the control and the highest concentration treatments. The control (A0) and the highest concentration (A4) exhibited markedly delayed emergence, with values exceeding 20 days in several observations. These differences demonstrate clear variability in sprouting performance among treatment combinations (Table 2). Similarly, the number of shoots was significantly affected by the interaction, with the highest mean value of 2.00 shoots per plant recorded in A3P1. Lower values were observed in control and several high-concentration treatments, depending on soaking duration (Table 3).

Plant height at 12 weeks after planting was not significantly affected by young coconut water concentration, soaking duration, or their interaction. However, variation in mean values was still observed across treatments. The highest plant height (82.75 cm) was recorded in A3 (75% concentration), while A2 and A1 also showed relatively high values. In contrast, the lowest plant height was observed in A4 (100% concentration), indicating reduced vegetative elongation at the highest concentration level (Table 4).

Number of leaves was significantly influenced by young coconut water concentration, while soaking duration and interaction effects were not significant. The highest mean leaf number was recorded in A2 (50% concentration) at 14.67 leaves per plant, followed closely by A3 at 14.14 leaves per plant. Lower values were observed in both control (A0) and A4 treatments, indicating reduced leaf formation at extreme concentration levels (Table 5).

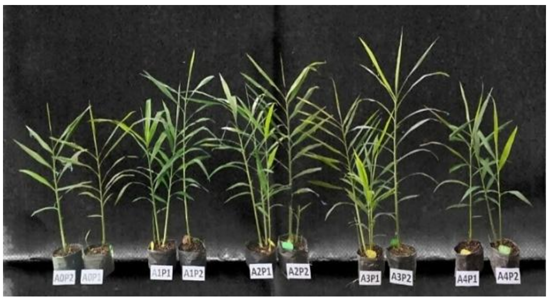

Fig 1. Representative growth of red ginger plants at 12 weeks after planting (WAP) under different young coconut water concentrations and rhizome soaking durations.

The overall vegetative growth performance of red ginger plants at 12 weeks after planting is presented in Figure 1, which illustrates representative plant morphology under different young coconut water concentrations and soaking durations. Differences in canopy development, leaf density, and general plant vigor among treatments can be visually distinguished, particularly between moderate concentration treatments and control or high-concentration treatments. Leaf greenness level, measured in SPAD units, showed no significant differences among treatments. Values ranged from 41.86 to 48.21 SPAD units, indicating relatively narrow variation across all treatment combinations (Table 6). Leaf area also did not differ significantly among treatments, with values ranging from 29.22 cm² to 34.04 cm² (Table 7). Similarly, root length was not significantly affected, ranging from 28.50 cm to 34.67 cm across all treatments, suggesting relatively stable root elongation regardless of treatment application (Table 8).

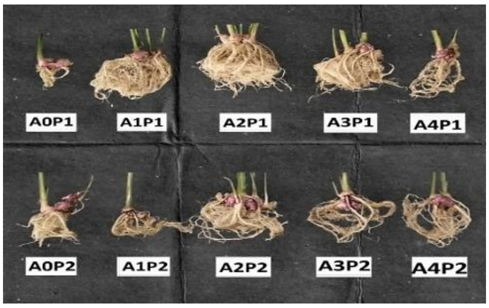

Fig 2. Root development of red ginger plants at 12 weeks after planting (WAP) under different young coconut water concentrations and rhizome soaking durations.

Root development responded significantly to both the interaction and the main effects of young coconut water concentration and soaking duration. Root fresh weight ranged widely from 4.75 g to 21.68 g per plant, with the highest value recorded in A2P1 (50% concentration with 12 h soaking duration). A similar trend was observed for root dry weight, which ranged from 0.85 to 3.28 g per plant, with the highest value also recorded in A2P1. These results indicate that moderate concentration combined with shorter soaking duration produced the highest root biomass accumulation among all treatments (Tables 9 and 10). Root morphological differences are further illustrated in Figure 2, which clearly shows variations in root system development among treatment combinations.

Shoot biomass production was significantly influenced by young coconut water concentration. Shoot fresh weight ranged from 20.63 g to 51.87 g per plant, with the highest value recorded in A3 (75% concentration). Shoot dry weight ranged from 3.59 g to 8.03 g per plant, with the highest mean value observed in A2 (50% concentration), followed closely by A3. Soaking duration and interaction effects were not significant for both parameters, indicating that concentration played a more dominant role in shoot biomass accumulation compared to soaking time (Tables 11 and 12). Shoot-to-root ratio was not significantly affected by young coconut water concentration, soaking duration, or their interaction. Values ranged from 0.72 to 1.31 across treatment combinations, reflecting relatively stable proportional distribution between shoot and root biomass among all treatment combinations (Table 13). Rhizome fresh weight was significantly affected by young coconut water concentration and soaking duration, whereas their interaction was not significant. The highest mean rhizome fresh weight of 33.35 g per plant was obtained at the 50% young coconut water concentration (A2), followed by the 75% concentration (A3) with 29.48 g per plant. In addition, 12 h soaking produced a higher mean rhizome fresh weight than 24 h soaking. Rhizome dry weight, however, was significantly influenced only by young coconut water concentration, with the highest mean value of 5.46 g per plant recorded at A2, followed by A3 and A1, whereas the control (A0) and the highest concentration (A4) produced lower values (Tables 14 and 15).

Table 1. ANOVA results of young coconut water concentration and soaking duration on red ginger growth.

Observed Variables	A	P	A x P	CV%
Time to Shoot Emergence	51,86**	4,15^{ns}	8,30**	10,70
Number of Shoots	1,36^{ns}	2,70^{ns}	2,98*	19,57
Plant Height (cm)	7,52^{ns}	7,00^{ns}	0,29^{ns}	12,59
Number of Leaves	4,24*	0,01^{ns}	0,68^{ns}	15,15
Leaf Greenness Level	2,21^{ns}	0,60^{ns}	0,04^{ns}	8,66
Leaf Area (cm²)	0,60^{ns}	0,20^{ns}	2,33^{ns}	17,74
Root Length (cm)	2,00^{ns}	0,15^{ns}	0,38^{ns}	15,76
Root Fresh Weight (g)	8,32**	12,44**	4,01*	38,13
Root Dry Weight (g)	6,71**	9,12**	3,71*	36,68
Shoot Fresh Weight (g)	17,43**	1,68^{ns}	2,89^{ns}	18,00
Shoot Dry Weight (g)	10,29**	0,39^{ns}	1,58^{ns}	19,17
Shoot–Root Ratio	2,39^{ns}	4,29^{ns}	2,04^{ns}	20,01
Rhizome Fresh Weight (g)	10,85**	7,48**	1,39^{ns}	14,27
Rhizome Dry Weight (g)	3,67*	1,72^{ns}	1,22^{ns}	19,52
F Table 5%	2,93	4,41	2,93	
Table 1%	4,58	8,29	4,58	

Note: ns = not significant; * = significant effect; ** = highly significant effect; CV = coefficient of variation. A = young coconut water concentration; P = soaking duration.

Table 2. Mean time to shoot emergence of red ginger at 4 WAP.

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	23,00 d	21,83 d	9,00 a	8,44 a	22,83 d	17,02
P2 (24 hours)	21,33 d	19,67 cd	12,67 b	16,66 c	21,83 d	18,43
Mean	22,17 b	20,75 b	10,84 a	12,55 a	22,33 b	

Note: Values followed by the same letter in the same row or column are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Table 3. Mean number of shoots of red ginger plants at 4 WAP.

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	1,33 a	1,50 ab	1,50 ab	2,00 b	1,17 a	1,50
P2 (24 hours)	1,33 a	1,50 ab	1,33 a	1,17 a	1,33 a	1,33
Mean	1,33	1,50	1,42	1,59	1,25	

Note: Values followed by the same letter in the same row or column are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Table 4. Mean plant height of red ginger at 12 WAP (cm).

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	61,67	69,67	78,83	75,50	56,50	68,43
P2 (24 hours)	69,50	81,17	84,17	90,00	61,67	77,30
Mean	65,59	75,42	81,50	82,75	59,09	

Note: Mean values are not followed by letters because the treatments showed no significant differences ($P > 0.05$) based on the analysis of variance.

Table 5. Mean number of leaves of red ginger plants at 12 WAP.

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	10,67	13,17	15,67	13,44	11,17	12,82
P2 (24 hours)	11,67	13,17	13,67	14,83	11,17	12,90
Mean	11,17 b	13,17 ab	14,67 a	14,14 a	11,17 b	

Note: Values followed by the same letter in the same row or column are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Table 6. Mean leaf greenness level of red ginger plants at 12 WAP (SPAD units).

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	46,96	49,11	47,68	45,53	41,97	46,25
P2 (24 hours)	45,81	47,31	45,93	44,86	41,74	45,13
Mean	46,39	48,21	46,81	45,20	41,86	

Note: Mean values are not followed by letters because the treatments showed no significant differences ($P > 0.05$) based on the analysis of variance.

Table 7. Mean leaf area of red ginger plants at 12 WAP (cm^2).

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	25,60	32,71	36,48	34,48	27,58	31,37
P2 (24 hours)	32,83	29,79	28,70	33,59	36,55	32,29
Mean	29,22	31,25	32,59	34,04	32,07	

Note: Mean values are not followed by letters because the treatments showed no significant differences (P > 0.05) based on the analysis of variance.

Table 8. Mean root length of red ginger plants at 12 WAP (cm).

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	28,83	30,83	35,83	33,50	26,83	31,16
P2 (24 hours)	29,17	31,50	32,67	35,83	30,17	31,87
Mean	29,00	31,17	34,25	34,67	28,50	

Note: Mean values are not followed by letters because the treatments showed no significant differences (P > 0.05) based on the analysis of variance.

Table 9. Mean root fresh weight of red ginger plants at 12 WAP (g).

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	5,28 d	15,10 abc	21,68 a	18,92 ab	4,75 d	13,15 a
P2 (24 hours)	5,57 d	5,62 d	11,38 bcd	8,97 cd	8,28 cd	7,96 a
Mean	5,43 c	10,36 bc	16,53 a	13,95 ab	6,52 c	

Note: Values followed by the same letter in the same row or column are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Table 10. Mean root dry weight of red ginger plants at 12 WAP (g).

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	0,96 d	2,49 abc	3,28 a	2,80 ab	0,85 d	2,08 a
P2 (24 hours)	0,98 d	1,05 d	2,00 bcd	1,32 cd	1,55 bcd	1,38 a
Mean	0,97 b	1,77 ab	2,64 a	2,06 ab	1,20 b	

Note: Values followed by the same letter in the same row or column are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Table 11. Mean shoot fresh weight of red ginger plants at 12 WAP (g).

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	23,45	36,92	51,87	47,05	20,63	35,98
P2 (24 hours)	24,87	29,77	36,72	45,77	28,12	33,05
Mean	24,16 c	33,35 b	44,30 a	46,41 a	24,38 c	

Note: Values followed by the same letter in the same row or column are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Table 12. Mean shoot dry weight of red ginger plants at 12 WAP (g).

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	4,49	6,12	8,03	6,97	3,59	5,84

P2 (24 hours)	4,20	5,22	6,33	7,31	4,81	5,57
Mean	4,35 bc	5,67 b	7,18 a	7,14 a	4,20 c	

Note: Values followed by the same letter in the same row or column are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Table 13. Mean shoot-root ratio of red ginger plants at 12 WAP.

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	0,99	1,00	0,86	0,97	0,72	0,91
P2 (24 hours)	0,98	0,84	1,25	1,31	0,91	1,06
Mean	0,99	0,92	1,06	1,14	0,82	

Note: Mean values are not followed by letters because the treatments showed no significant differences ($P > 0.05$) based on the analysis of variance.

Table 14. Mean rhizome fresh weight of red ginger plants at 12 WAP (g).

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	20,80	29,98	34,48	32,08	24,08	28,28 a
P2 (24 hours)	20,20	20,53	32,22	26,88	22,78	24,52 a
Mean	20,50 c	25,26 bc	33,35 a	29,48 ab	23,43 c	

Note: Values followed by the same letter in the same row or column are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Table 15. Mean rhizome dry weight of red ginger plants at 12 WAP (g).

Soaking duration	Young coconut water concentration					
	A0 (0%)	A1 (25%)	A2 (50%)	A3 (75%)	A4 (100%)	Mean
P1 (12 hours)	3,73	5,09	5,30	4,77	4,08	4,59
P2 (24 hours)	3,70	3,40	5,62	4,28	3,92	4,18
Mean	3,72 b	4,25 b	5,46 a	4,53 a	4,00 b	

Note: Values followed by the same letter in the same row or column are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% significance level.

4. Discussion

4.1. Early Growth

Research results indicate that young coconut water concentrations of 50–75% have a highly significant effect on the time of shoot emergence. This response is thought to be associated with the presence of growth-promoting compounds naturally found in young coconut water. Several previous studies have noted that young coconut water contains various compounds with the potential to support growth and shoot development. According to Asra et al. [8], gibberellins have been reported to promote germination by stimulating amylase enzyme activity, while cytokinins may contribute to shoot emergence and shoot differentiation into leaves [9]. However, the number of shoots did not differ significantly among treatments. This result suggests that endogenous factors stored within red ginger rhizomes may have been sufficient to support early plant growth. Rusmin et al. [10] explained that rhizomes function as storage organs containing starch reserves and endogenous hormones such as IAA, gibberellins, cytokinins, and ABA, which have been associated with plant viability and early growth.

The soaking duration alone did not significantly affect the early shoot growth parameters. This condition was likely related to the occurrence of a saturation point within the rhizome tissues. Based on the triphasic imbibition theory proposed by Liu et al. [11], plant tissues enter a plateau phase after rapid water absorption, during which cell turgidity reaches its maximum level. As a result, the movement of water and dissolved hormones into the rhizome tissues becomes limited, reducing the effectiveness of additional hormone uptake during the initial growth stage.

The interaction between young coconut water concentration and soaking duration significantly affected the time to shoot emergence and the number of shoots. This indicates that the growth response is influenced not only by the concentration of young coconut water but also by the duration of rhizome soaking. The interaction between young coconut water concentration and soaking duration enhanced early growth responses of red ginger, with the 75% concentration combined with a 12-hour soaking duration producing the fastest shoot emergence and the highest number of shoots. Afriyanty et al. [12] reported that organic nutrients can maintain the optimal activity of hormones contained in coconut water, thereby supporting early plant development.

4.2. Vegetative Growth

Young coconut water concentrations of 50–75% showed significant to highly significant effects on leaf number, shoot fresh and dry weights, root fresh and dry weights, and rhizome fresh and dry weights. The increase in shoot fresh and dry weights at that concentration indicates enhanced vegetative plant growth. This response is thought to be associated with growth-promoting compounds present in young coconut water, as reported in several previous studies. These findings are consistent with the study of Limbongan and Tambing [6], which reported that the application of natural plant growth regulators derived from young coconut water at a 75% concentration produced the most favorable growth response in red ginger. In contrast, parameters such as plant height, leaf greenness level, leaf area, and shoot–root ratio were not significantly affected. Exogenous growth-promoting substances may provide limited effects when endogenous physiological factors within plant tissues are already sufficient to support growth. The availability of stored nutrients and endogenous hormones in rhizomes may enable plants to sustain vegetative growth independently [10].

The research results indicate that the duration of soaking has a highly significant effect on the fresh and dry weights of roots and the fresh weight of rhizomes. Soaking for 12 hours yielded a more optimal growth response compared to 24 hours. This suggests that a 12-hour soaking period is more effective at facilitating the uptake of water and dissolved compounds into the rhizome tissue than a 24-hour soak. Asra et al. [8] stated that the absorption of growth-promoting compounds plays an important role in supporting root growth. However, other vegetative parameters, including plant height, number of leaves, and leaf area, were not significantly influenced by soaking duration. This condition was likely associated with reduced water absorption during the plateau phase, in which additional hormone uptake no longer contributed substantially to plant growth responses.

The interaction between young coconut water concentration and soaking duration significantly affected root fresh and dry weights. This indicates that the hormone's effectiveness is influenced by both the concentration and the duration of rhizome soaking. A combination of 50% young coconut water concentration and a 12-hour soaking duration produced the highest root fresh and dry weights, indicating its effectiveness in promoting root development and biomass accumulation during the early growth stage. These findings regarding the treatment interaction align with the study by Afriyanty et al. (2024) on shallots, which demonstrated that the right combination of concentration and soaking duration enhances the effectiveness of the natural hormones found in coconut water, thereby optimizing shoot and root growth.

5. Conclusions

Based on the results of this study, it can be concluded that:

1. A young coconut water concentration of 50% was the most effective treatment overall, as it produced the best response in several key growth parameters, including leaf number, root fresh weight, root dry weight, shoot dry weight, rhizome fresh weight, and rhizome dry weight. Although the 75% concentration resulted in faster shoot emergence and a greater number of shoots, the 50% concentration provided more consistent improvements in overall plant growth and biomass accumulation.
2. A 12-h rhizome soaking duration was more effective than a 24-h soaking duration in increasing root fresh weight, root dry weight, and rhizome fresh weight of red ginger.
3. The interaction between a 50% young coconut water concentration and a 12-h soaking duration produced the highest root fresh and root dry weights, indicating superior root development during the early growth stage.

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References

[1] B. N. Amaliah, M. Irfan, J. Mutakin, N. Sativa, Respons pertumbuhan bibit jahe merah (*Zingiber officinale* var. *rubrum*) terhadap waktu perendaman dan konsentrasi *Plant Growth Promoting Rhizobacteria* (PGPR). Agroteknika 6, 213–225 (2023). https://agroteknika.id/index.php/agtk/article/view/225

[2] Badan Pusat Statistik. 2025, Statistik tanaman biofarmaka Indonesia (Badan Pusat Statistik, Jakarta, 2025). https://www.bps.go.id/id

[3] S.T. Wardana, J. Juswardi, N.L.A. Rama, Pengaruh pertumbuhan rimpang jahe merah (*Zingiber officinale* var. *rubrum*) pada perendaman auksin dan PGPR (*Plant Growth Promoting Rhizobacteria*). Sriwijaya Bioscientia 2, 53–58 (2021). https://doi.org/10.24233/sribios.2.2.2021.354

[4] S. Rosniawaty, I.R.D. Anjarsari, R. Sudirja, Aplikasi sitokinin untuk meningkatkan pertumbuhan tanaman teh di dataran rendah. J. Tanam. Ind. Penyegar 5, 31–38 (2018). https://www.neliti.com/publications/238432/application-of-cytokinins-to-enhance-tea-plant-growth-in-the-lowlands#id-section-content

[5] E. Ernawati, P. Rahardjo, B. Suroso, Respon benih cabai merah (*Capsicum annuum* L.) kadaluarsa pada lama perendaman air kelapa muda terhadap viabilitas, vigor dan pertumbuhan bibit. Agritrop 15, 273–282 (2017). https://jurnal.unmuhjember.ac.id/index.php/AGRITROP/article/view/794

[6] Y. Limbongan, Y. Tambing, Pengaruh bobot rimpang dan ZPT alami air kelapa terhadap pertumbuhan jahe merah (*Zingiber officinale* var. *rubrum*). AgroSaint UKI Toraja 9, 48–61 (2018). https://journals.ukitoraja.ac.id/index.php/agro/article/view/571/455

[7] F. Rokhmah, Pengaruh konsentrasi zat pengatur tumbuh air kelapa muda terhadap pertumbuhan beberapa varietas jahe (*Zingiber officinale* Rosc.). Biofarm J. Ilm. Pertan. 15, 65–70 (2019). https://doi.org/10.31941/biofarm.v15i2.1142

[8] R. Asra, R.A. Samarlina, M. Silalahi, *Hormon tumbuhan* (UKI Press, Jakarta, 2020). http://repository.uki.ac.id/id/eprint/1579

[9] A. Muaningrat, S. Nada, Pengaruh konsentrasi zat pengatur tumbuh dalam kandungan air kelapa terhadap pertumbuhan tanaman jahe (*Zingiber officinale*) dan tanaman kencur (*Kaempferia galanga* L.). in Proceedings of Seminar Nasional Biologi 9, 1–9 (2021). https://proceedings.unnes.ac.id/semnasbiologi/article/view/750/659

[10] D. Rusmin, M.R. Suhartanto, S. Ilyas, D. Manohara, E. Widajati, Karakteristik pola pertumbuhan, biokimia dan fisiologi untuk penentuan umur panen rimpang benih jahe putih besar. Bull. Penelit. Tanam. Rempah Obat 29, 9–20 (2018). https://www.cabidigitallibrary.org/doi/pdf/10.5555/20203219363

[11] L. Liu, Z. Wang, Y. Wu, Y. Shen, Hormonal and storage metabolic regulation of germination in *Toona sinensis*. Horticulturae 11, 685 (2025). https://doi.org/10.3390/horticulturae11060685

[12] N. Afriyanty, S. Suriyanti, A. Ralle, Pengaruh konsentrasi air kelapa dan lama perendaman benih terhadap peningkatan pertumbuhan dan produksi tanaman bawang merah (*Allium ascalonicum* L.). AGrotekMAS J. Indones. J. Ilmu Pertan. 5, 305–311 (2024). https://jurnal.fp.umi.ac.id/index.php/agrotekmas