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Study on the Effect of NAA Concentration and Application Frequency on Shoot Growth of Porang Tuber Cuttings (*Amorphophallus muelleri* Blume)

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Abstract

Increasing industrial demand for porang requires efficient propagation strategies, such as tuber cuttings combined with NAA application to enhance shoot and root development. This study aimed to evaluate the effects of NAA concentration and application frequency on the growth of porang tuber cuttings. The experiment was conducted from July to December 2024 in Pagar Merbau III Village, Lubuk Pakam District, and at the Biotechnology Laboratory, Faculty of Agriculture, University of North Sumatra, using a two-factor Randomized Block Design with three replications. The treatments consisted of four levels of NAA concentration (0, 50, 100, and 150 ppm) and two application frequencies (single application at the beginning of the nursery stage and repeated application at the beginning of the nursery stage and 7 days after sowing). Observed variables included shoot emergence percentage, plant growth, biomass, tuber weight, chlorophyll content, and stomatal density. Data were analyzed using ANOVA followed by Duncan's Multiple Range Test at a 5% significance level. The results showed that the application of NAA at 100 ppm significantly enhanced shoot growth, plant height, fresh and dry weight, chlorophyll content, and stomatal characteristics. A single application at the early nursery stage produced optimal results in plant height, tuber weight, and chlorophyll content, while repeated application increased the number of shoots, vegetative growth, and biomass accumulation. The interaction between 100 ppm NAA and early application resulted in the best performance in leaf number at 3 weeks after planting and tuber weight.

Keywords: *Concentration, frequency, NAA, porang.*

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INTRODUCTION

Porang (*Amorphophallus muelleri* Blume) is a tuber crop with high economic value and has begun to be widely developed by farmers because it can increase farm income. The cultivation of porang is strongly supported by Indonesia's favorable agricultural climate (Ikayanti et al., 2021). Porang, also known as iles-iles, is classified as a shrub-type plant with a height of 1 to 1.5 meters. The stem grows upright, has a soft and smooth texture, and is marked with green lines or white spots around the stem. The main stem can produce three secondary branches that continue to develop along with leaf growth. The tuber skin is dark brown, while the tuber flesh is yellow to orange in color (Anturida & Azrianingsih, 2015). This plant is easy to cultivate, requires high shade, uses land efficiently, and grows optimally under tree canopies in agroforestry systems (Permadi, 2012).

Indonesia has great potential for porang cultivation for food, industrial, and health purposes. This crop has high economic value, and its demand continues to increase, both in fresh and dried forms (Puspitorini, 2019). Porang tubers are rich in nutrients, and production in East Java reaches 2,000 tons of

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fresh tubers from 7,006 hectares of land. However, to meet industrial demand of 3,400 tons of porang chips, further expansion of cultivation is still required. Increasing the availability of high-quality and sufficient porang planting material is essential to support future production growth. Porang can be propagated generatively through seeds or vegetatively using tubers and bulbils (Ganjari, 2014). Generative propagation using seeds has the potential to produce many plants but faces constraints such as seed dormancy lasting 1–2 months, a long harvesting period (3–4 years), and uneven growth. Meanwhile, vegetative propagation using sprouted tubers or shoots also requires a long time and a large number of tubers. Therefore, more efficient nursery methods are needed to meet farmers' demand for planting material.

Vegetative propagation through tuber cuttings that possess bud eyes on the tuber skin is considered more efficient because it accelerates the nursery process and reduces dependence on small tubers that produce only one tuber. Porang tubers are oval in shape, with outer skin ranging from yellowish-brown to reddish-brown and dark yellow flesh. The skin surface is rough and fibrous and easily peels when dried. In addition, the tubers contain calcium oxalate crystals that can cause skin irritation if not properly processed. Propagation through tuber cutting techniques can produce a larger number of seedlings within a relatively short period. Increasing porang productivity requires the availability of sufficient and high-quality seedlings. Successful seedling establishment depends on the simultaneous and healthy acceleration of shoot and root growth. One effort to achieve this is through the application of plant growth regulators (PGRs), which play a role in breaking dormancy and stimulating shoot growth. PGRs influence both internal factors (physiological, genetic, and hormonal) and external factors (temperature, humidity, and wounding), thereby accelerating shoot emergence and reducing tuber dormancy periods (Hidayat, 2020).

Auxins, as growth-regulating hormones, play an important role in vegetative propagation, particularly by stimulating root and shoot formation in cuttings. Several types of auxins commonly used in plant propagation include Indole Acetic Acid (IAA), Indole-3-Butyric Acid (IBA), α-Naphthalene Acetic Acid (NAA), and 2,4-Dichlorophenoxyacetic Acid (2,4-D) (Karyanti, 2017). NAA, a synthetic auxin, is more stable and persists longer in plants compared to other auxins, making it more effective in stimulating root and shoot growth (Madhiyetti et al., 2015). Therefore, the application of NAA at specific concentrations can accelerate porang cutting propagation and increase root number and quality (Fitriani, 2008).

Based on the above description, this study was conducted to examine the effects of varying concentrations and application frequencies of the auxin NAA on the growth of porang tuber cuttings (Amorphophallus muelleri Blume).

MATERIALS AND METHODS

Place and Time

This research activity was conducted on Jalan Galang, Pagar Merbau III Village, Lubuk Pakam Subdistrict, Deli Serdang Regency, North Sumatra, and at the Biotechnology Laboratory, Faculty of Agriculture, Universitas Sumatera Utara, Medan. The study was carried out from July to December 2024.

Materials and Tools

The materials used consisted of porang tubers as planting material, a nursery medium of soil mixed with cocopeat, soil as the planting medium in polybags, polybags (20 × 20 cm), NAA auxin as a plant growth regulator, NaOH as a solvent, bamboo as shading support, and paranet as a shading cover.

The tools used included a knife as a cutting tool for peeling the skin of porang tubers, gloves as protective equipment to prevent itching caused by porang tubers, containers as seedling trays, a hand sprayer for applying the auxin plant growth regulator, a measuring tape to measure the land area, a hoe for preparing the planting material, a watering can or bucket for watering the plants, and other equipment (ruler, labels, camera, and writing tools) for observations during the research activities.

Research Design

The experiment was arranged in a two-factor Randomized Block Design (RBD) with three replications. The first factor was NAA concentration consisting of four levels: A0 = control, A1 = 50 ppm, A2 = 100 ppm, and A3 = 150 ppm. The second factor was spraying frequency consisting of two levels: P1 = application at the beginning of the nursery stage and P2 = application at the beginning of the nursery stage and 7 days after sowing.

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This resulted in 8 treatment combinations with a total of 24 experimental plots (8 × 3). Each plot consisted of 9 plants, with 5 plants selected as observation samples, resulting in a total of 120 sample plants (from 216 experimental plants).

Preparation of Cutting Material

The planting materials were porang tubers obtained from healthy plants with relatively uniform size and physiological condition to ensure seedling homogeneity. Tubers weighing approximately 2 kg were cut into several sections (tuber cuttings) with a thickness of about 3 cm, each containing approximately 15 buds. These cuttings were sown in a nursery medium consisting of soil mixed with cocopeat. The number of tubers sown was adjusted to meet the total requirement of 216 plants, with additional reserves prepared for replanting. The nursery period lasted approximately 2–3 weeks after sowing until shoots were ready for transplanting.

Land preparation was carried out by clearing weeds and tilling the soil to improve its structure. A paranet providing approximately 50% shading was installed to support optimal porang growth. The planting medium (soil) was then filled into polybags measuring 20 × 20 cm.

Preparation of Auxin Solution

NAA was applied using a hand sprayer according to the treatment concentrations (0, 50, 100, and 150 ppm). A total of 216 plants were subjected to NAA treatments in accordance with the experimental design. The stock solution of NAA (100 ppm) was prepared by dissolving 10 g of NAA powder in a 100 mL Erlenmeyer flask, adding a few drops of 1 N NaOH to facilitate dissolution, followed by 50 mL of distilled water. After complete dissolution, distilled water was added to reach a final volume of 100 mL. The application was carried out at the beginning of the nursery stage (P1), and for P2 treatment, it was repeated at 7 days after sowing.

Planting

After shoots emerge, 2-3 weeks after sowing, the shoots are ready to be transplanted. Germinated tuber cuttings are transferred into polybags, with one cutting per bag. Plant maintenance includes regular watering to support optimal growth conditions, without additional fertilizer. Pest and disease control in porang plants is carried out manually and, if necessary, through the application of insecticides or fungicides, depending on field conditions.

Observation Parameters

The observed parameters included plant height, number of leaves, stem diameter, root length, shoot fresh weight, root fresh weight, shoot dry weight, root dry weight, tuber weight, chlorophyll content, stomatal density and shoot emergence percentage was calculated based on the percentage of cuttings that grew normally on the first day of observation (day of emergence). The percentage of shoot emergence was calculated using the following formula:

$$Shoot\ emergence\ percentage = \frac{Number\ of\ normal\ emerging\ buds}{Total\ number\ of\ sprouted\ cuttings}\ x\ 100\%$$

Data Analysis

Data were analyzed using analysis of variance (ANOVA), and if significant differences were observed, further analysis was conducted using Duncan's Multiple Range Test (DMRT) at a significance level of α = 5%.

RESULTS AND DISCUSSION

Shoot Emergence Percentage (%)

Shoot emergence percentage (%) was determined by counting the number of sprouts that emerged and developed from the buds of porang tuber cuttings. Observations were conducted weekly, and the data were expressed as percentages and subsequently averaged. The shoot emergence percentage was calculated using the formula: (number of emerged sprouts / total number of planted tuber cuttings) × 100%. The use of percentage values allows for a more accurate comparison of sprouting success among treatments by standardizing the data relative to the total number of planting materials. A

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sprout was considered valid if it exhibited normal growth characteristics, such as upright growth and the presence of roots.

The results showed that NAA concentration had a significant effect on shoot emergence percentage, whereas the frequency of NAA application and the interaction between both factors did not significantly affect this parameter. The mean values are presented in Table 1.

Table 1. Shoot Emergence Percentage Under Treatments of NAA Auxin Concentration and Application Frequency on Porang

Concentration of NAA	Frequency on NAA		Average
	At the Beginning of nursery (P1)	At the beginning of nursery and 7 days after sowing (P2)	
	……………………..%………………………		
Control (A0)	44.44	51.85	48.15c
50 ppm (A1)	66.67	70.37	68.52b
100 ppm (A2)	85.19	88.89	87.04a
150 ppm(A3)	48.15	48.15	48.15c
Average	61.11	64.81	

Note: Values followed by different letters for each different treatment indicate a significant difference based on Duncan's Multiple Range Test at the 5% level.

Germination and shoot emergence are influenced by various internal factors, such as hormones, seed condition, and physical damage, as well as external factors including temperature, light, soil conditions, oxygen, and humidity (Turhadi and Indrityani, 2015). As shown in Table 1, the highest shoot emergence percentage was obtained at the NAA concentration of 100 ppm, with a mean value of 87.04%, which was significantly different from the other concentrations. Meanwhile, the spraying frequency treatment at the beginning of the nursery and 7 days after sowing (P2) resulted in the highest average value of 64.81%, although it was not significantly different from the other frequency treatments.

The high shoot emergence percentage at 100 ppm indicates that this concentration was optimal in stimulating sprout formation from porang tuber cuttings. This effect is associated with the role of auxin in promoting cell division and elongation, which accelerates both shoot and root initiation. Improved root development enhances nutrient and water uptake, thereby supporting early shoot growth and establishment. Auxin is known to stimulate root formation through increased cell division and elongation activity (Erliandi et al., 2015; Alfiansyah et al., 2015), while the application of exogenous auxin can also enhance the activity of endogenous auxin, leading to faster and more uniform shoot emergence.

In addition, NAA has been reported to accelerate explant responses in shoot formation, as observed in porang micropropagation studies (Prayana et al., 2017). Faster shoot emergence contributes to more efficient plant growth, as early shoot development allows for quicker formation of photosynthetic organs, which subsequently support further growth through assimilate production and hormonal regulation.

Porang Plant Height (cm)

The results of the analysis showed that NAA auxin concentration had a significant effect on plant height at 1–10 Weeks After Transplanting (WAT), while application frequency and their interaction had no significant effect. The mean data on porang plant height under treatments of NAA auxin concentration and frequency are presented in Table 2.

In porang plants, height development during the early stage (1–3 WAP) is not yet significant because measurements begin only after leaf emergence. At this phase, buds are still covered by protective membranes that later dry and peel off. Around 4 WAP, apical buds emerge, indicated by the opening of the outer bracteae, marking the end of dormancy (Gusmalawati, 2021).

As shown in Table 2, plant height from 6 to 10 WAT fluctuated, reflecting the non-linear growth pattern of porang during early vegetative stages. These fluctuations may result from variations in leaf orientation, temporary growth stagnation, measurement differences, and environmental factors such as light, humidity, and plant adaptation after transplanting. At 10 WAT, the 50 ppm NAA treatment produced the highest plant height (56,82 cm), while the 150 ppm treatment resulted in the lowest height (22,89 cm). This indicates that NAA concentration strongly influences plant growth. At low concentrations, auxin stimulates cell division and elongation, whereas excessive concentrations inhibit these processes.

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Table 2. Porang Plant Height as Affected by Treatments of NAA Auxin Concentration and Application Frequency at 1–10 Weeks After Transplanting (WAT) (Growth of Cutting Seedlings)

Concentration on NAA	Weeks After Transplanting (WAT)									
	1	2	3	4	5	6	7	8	9	10
	……………………cm……………………									
Control (A0)	0.00c	0.00c	2.03c	15.10b	21.62bc	21.58b	20.03c	21.84b	20.21b	18.11c
50 ppm (A1)	22.50a	26.56a	32.60a	35.21a	40.35a	44.01a	41.76a	44.57a	42.88a	41.05a
100 ppm (A2)	9.42b	10.28b	19.84b	27.88a	34.06ab	37.12ab	37.63ab	33.28b	32.34ab	33.12ab
150 ppm(A3)	2.25bc	2.62bc	3.68c	10.02b	16.99c	24.60b	26.77bc	29.27b	25.94b	22.89bc
Frequency on Auxin NAA										
At the Beginning of nursery (P1)	8.20	10.54	15.70	21.63	27.07	30.93	32.66	31.76	30.36	27.36
At the beginning of nursery and 7 days after sowing (P2)	8.89	9.19	13.38	22.47	29.44	32.72	30.43	32.72	30.32	30.23
Interaction	tn	tn	tn	tn	tn	tn	tn	tn	tn	tn

Note: Values followed by different letters for each different treatment indicate a significant difference based on Duncan's Multiple Range Test at the 5% level.

High NAA levels can increase ethylene production, which interferes with auxin activity and suppresses cell elongation and meristematic activity (Alfiansyah et al., 2015). This condition reduces root formation, nutrient uptake, and photosynthetic efficiency (Harjanti et al., 2014). In addition, excessively high NAA concentrations can inhibit cell elongation because the plant's endogenous hormones are already sufficient, so the addition of external hormones does not produce a significant effect (Suhardjito, 2017). High doses of plant growth regulators can also be toxic and disrupt the function of natural plant hormones (Kumar et al., 2023); Asra et al., 2020). Auxin itself plays a role in cell elongation, division, differentiation, and root formation, with the strongest effects in the shoot apical meristem (Astutik, 2021). However, when present in excessive amounts, it can instead inhibit growth.

The frequency of NAA application did not have a significant effect on increasing plant height, with the highest results obtained from the treatment sprayed at the beginning of the nursery stage. This is because the application of plant growth regulators to porang plants can promote growth and increase plant performance. NAA auxin, as a type of plant growth regulator, functions to stimulate cell division, increase the plasticity and elasticity of cell walls, and regulate flowering. If auxin is applied at excessively high concentrations, it can inhibit cell growth and development. Increasing the frequency of NAA application can also slow plant growth. Spraying in treatment at the beginning of nursery and 7 days after sowing results in a higher overall concentration. Excessive levels of plant growth regulators can stimulate ethylene synthesis, which subsequently accelerates the aging (senescence) process and causes damage to plant tissues. This condition leads to reduced plant viability and inhibited growth. Masood et al. (2012) and Nazar et al. (2014) stated that ethylene is a plant growth regulator that accelerates senescence and inhibits plant growth.

Number of Porang Leaves (Leaves)

The results of the analysis showed that NAA auxin concentration had a significant effect on the number of leaves at 1–4 Weeks After Transplanting (WAT), and the interaction between the two factors had a significant effect on the number of leaves at 3 WAT. The frequency of NAA application did not have a significant effect on the number of leaves at 1–10 WAT. The mean data on the number of porang leaves under treatments of NAA auxin concentration and frequency are presented in Table 3.

At the early growth stage (1–3 Weeks After Transplanting/WAT), porang plants did not show significant development in leaf number, particularly in the control treatment. The number of leaves only began to increase at 4 WAT. This condition occurs because, during the initial phase, plants primarily utilize stored food reserves from the tuber and allocate energy for root formation rather than the development of aboveground organs such as leaves (Sulasiah et al., 2015).

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Table 3. Number of Porang Leaves as Affected by Treatments of NAA Auxin Concentration and Application Frequency at 1–10 Weeks After Transplanting (WAT)

Concentration on NAA	Weeks After Transplanting (WAT)									
	1	2	3	4	5	6	7	8	9	10
	……………………leaves……………………									
Control (A0)	0.00b	0.00b	0.00b	3.17b	2.42	2.45	9.33	10.08	10.14	10.03
50 ppm (A1)	1.67b	1.72b	6.57a	10.64a	3.39	3.43	11.61	12.73	13.20	14.07
100 ppm (A2)	6.67a	6.17a	8.30a	11.32a	3.44	3.52	11.92	12.09	12.20	12.37
150 ppm(A3)	0.00b	0.00b	1.00b	1.50b	2.74	2.80	9.90	10.11	9.80	9.91
Frequency on Auxin NAA										
At the Beginning of nursery (P1)	2.17	1.67	3.48	6.76	10.74	10.87	10.07	10.66	10.66	10.79
At the beginning of nursery and 7 days after sowing (P2)	2.00	2.28	4.45	6.56	13.25	13.52	11.32	11.85	12.01	12.40
Interaction	tn	tn	*	tn	tn	tn	tn	tn	tn	tn

Note: Values followed by different letters for each different treatment indicate a significant difference based on Duncan's Multiple Range Test at the 5% level.

At 4 WAT, leaf development increased markedly. The highest number of leaves was observed in the 100 ppm NAA treatment with a mean of 11,32 leaves, which was not significantly different from the 50 ppm treatment with a mean of 10,64 leaves. This indicates that appropriate concentrations of NAA are effective in stimulating vegetative growth, particularly leaf formation. Auxin plays an important role in promoting cell division and elongation, thereby accelerating leaf development (Miftah et al., 2022).

The interaction between NAA concentration and application frequency showed a significant effect at 3 WAT. The highest number of leaves (12,40 leaves) was found in the combination of 50 ppm NAA concentration with two applications (at the beginning of nursery and 7 days after sowing). This suggests that repeated application at the appropriate concentration enhances plant response to hormones and improves vegetative growth (Setiawan, 2017; Adawiah et al. 2023). Similar findings were reported by Khusni (2023), who stated that auxin application at multiple growth stages is more effective in increasing vegetative growth.

However, at 8–10 WAT, the number of leaves decreased, especially at higher NAA concentrations (150 ppm). This decline is mainly associated with the transition from the vegetative to the generative phase, indicated by tuber formation. During this phase, assimilates are redirected toward tuber development rather than leaf formation, resulting in reduced vegetative growth (Nurdinah, 2024). In addition, porang plants naturally experience leaf senescence, where older leaves age, wilt, and eventually fall. High concentrations of NAA may also stimulate excessive ethylene production, which accelerates senescence and leaf abscission, thereby further reducing the number of leaves. Overall, these results indicate that optimal NAA concentration and appropriate application frequency are essential for promoting leaf growth in porang. Low to moderate concentrations (50–100 ppm) tend to enhance vegetative development, whereas excessively high concentrations (150 ppm) can inhibit growth and accelerate senescence, leading to a decrease in leaf number.

Stem Diameter or Porang Plants (mm)

The results of the analysis showed that NAA auxin concentration had a significant effect on increasing stem diameter at 3–10 Weeks After Transplanting (WAT). The frequency of NAA application and the interaction between the two factors did not have a significant effect on stem diameter. The mean data on porang stem diameter under treatments of NAA auxin concentration and frequency are presented in Table 4.

The increase in stem diameter can be used as a primary indicator in assessing plant growth. The application of NAA auxin at certain concentrations is able to initiate stem growth. When the auxin concentration applied is appropriate, stem diameter will increase due to faster cell division, which enlarges the stem diameter of porang plants. Stem diameter and plant height are closely related, if the

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plant is shorter than normal, the stem diameter tends to be larger than usual (Syahputra, 2021). The stem serves as a site for the accumulation of growth products, especially in the early growth stage when nutrients are available, resulting in more optimal vegetative growth (Satria et al., 2015).

Table 4. Stem Diameter of Porang Plants as Affected by Treatments of NAA Auxin Concentration and Application Frequency at 3 - 10 Weeks After Transplanting (WAT)

Concentration on NAA	Weeks After Transplanting (WAT)							
	3	4	5	6	7	8	9	10
	……………………………………………mm……………………………………………							
Control (A0)	0.00b	2.05b	5.80b	7.67b	8.56b	8.80b	9.40b	10.37bc
50 ppm (A1)	5.69a	7.53a	9.19ab	9.58ab	9.99ab	10.61a	11.17a	11.75ab
100 ppm (A2)	8.33a	10.03a	10.14a	11.05a	11.48a	12.10a	12.63a	13.56a
150 ppm(A3)	1.77b	1.82b	6.60ab	7.63b	8.51b	8.51b	9.02b	9.55c
Frequency on Auxin NAA								
At the Beginning of nursery (P1)	4.23	5.73	6.98	9.00	9.64	9.81	10.45	11.37
At the beginning of nursery and 7 days after sowing (P2)	3.66	4.99	8.89	8.96	9.63	10.15	10.66	11.24
Interaction	tn	tn	*	tn	tn	tn	tn	tn

Note: Values followed by different letters for each different treatment indicate a significant difference based on Duncan's Multiple Range Test at the 5% level.

The results showed that porang plants at 10 Weeks After Transplanting (WAT) had the largest stem diameter in the 100 ppm concentration treatment with a mean of 13,56 mm, which was not significantly different from the 50 ppm concentration treatment with a mean of 11,75 mm. Table 4 shows that the widest stem diameter at 10 WAT was found in the spraying frequency treatment at the beginning of nursery with a mean of 11,37 mm. This is presumed to occur because the application of NAA at high concentrations can inhibit plant growth by reducing cell division and cell enlargement. Porang plants, as monocotyledons, undergo stem thickening through the division and enlargement of ground parenchyma cells rather than through secondary growth in the cambium. Inhibition of division and elongation of ground parenchyma cells can result in a reduction in stem diameter (Frasiandini et al., 2012).

Root Length, Root and Shoot Fresh Weight, Root and Shoot Dry Weight, and Tuber Weight

The results of the analysis showed that NAA auxin concentration had a significant effect on root length, root fresh weight, shoot fresh weight, root dry weight, shoot dry weight, and tuber weight. The frequency of NAA application did not have a significant effect on root length, root fresh weight, shoot fresh weight, root dry weight, shoot dry weight, and tuber weight. The interaction between the two factors had a significant effect on increasing tuber weight. The mean data on root length, root fresh weight, shoot fresh weight, root dry weight, shoot dry weight, and porang tuber weight under treatments of NAA auxin concentration and frequency are presented in Table 5.

Table 5 shows that the longest porang root length was obtained at 100 ppm with 51,53 cm, which was not significantly different from 50 ppm at 44,29 cm. Based on spraying frequency, the highest root length was observed in early nursery and 7 DAS with 41,18 cm. This result is likely due to the second spraying increasing NAA uptake, thereby stimulating plant growth. Root formation begins with the metabolism of stored carbohydrates, which provide energy for cell division and formation (Sulasiah et al., 2015).

The highest root fresh weight was recorded at A2 (19,90 g), not significantly different from 50 ppm treatment (19,36 g), while in early nursery and 7 DAS produced 17,92 g. Similarly, shoot fresh weight was highest at 100 ppm treatment (32,92 g), not significantly different from 50 ppm treatment (25,93 g), with in early nursery and 7 DAS at 24,67 g. Root dry weight was highest at 100 ppm treatment (3,16 g), not significantly different from 50 ppm treatment (2,18 g), with in early nursery and 7 DAS at 2,15 g. Shoot dry weight reached the highest value at 100 ppm treatment (7,28 g) and was significantly different from other treatments, while in early nursery and 7 DAS resulted in 5,24 g.

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Table 5. Root Length, Root Fresh Weight, Shoot Fresh Weight, Root Dry Weight, Shoot Dry Weight, and Tuber Weight Under Treatments of NAA Auxin Concentration and Application Frequency on Porang at 10 Weeks After Transplanting (WAT)

Concentration on NAA	Root Length (cm)	Root Fresh Weight (g)	Shoot Fresh Weight (g)	Shoot Dry Weight (g)	Root Dry Weight (g)	Tuber Weight (g)
Control (A0)	34.39b	12.41b	17.81,b	1.20b	2.93b	11.39c
50 ppm (A1)	44.29a	19.36a	25.93ab	2.18ab	4.06b	22.14b
100 ppm (A2)	51.53a	19.90a	32.92a	3.16a	7.28a	33.95a
150 ppm (A3)	30.83b	12.79b	20.66b	1.22b	4.18b	14.07bc
Frequency on NAA						
At the Beginning of nursery (P1)	39.34	14.31	23.99	1.73	3.98	20.49
At the beginning of nursery and 7 days after sowing (P2)	41.18	17.92	24.67	2.15	5.24	20.29
Interaction	tn	tn	tn	tn	tn	*

Note: Values followed by different letters for each different treatment indicate a significant difference based on Duncan's Multiple Range Test at the 5% level.

Overall, the application of 100 ppm NAA increased root and shoot fresh and dry weights. This improvement is attributed to the expansion of the root absorption area, which enhances the plant's ability to absorb essential nutrients. Root fresh weight reflects the capacity of roots to absorb water and nutrients, whereas shoot fresh weight indicates biomass accumulation in aboveground organs such as leaves, stems, and branches. In contrast, the application of 150 ppm NAA tended to inhibit cell division, suppress vegetative growth, and reduce photosynthetic efficiency, leading to lower fresh and dry weights. Indri (2007) reported that growth inhibition during early stages can reduce biomass production, resulting in fewer and smaller leaves and decreased photosynthesis. Since both fresh and dry weights are accumulations of photosynthates, any disruption in physiological processes will directly affect plant weight (Lehar et al., 2024).

Regarding spraying frequency, early nursery and 7 DAS produced better results than only at early nursery. More frequent NAA application enhances plant physiological activity. The first spraying stimulates cell division and elongation, while the second application supports hormonal needs during metabolic transition. According to Taiz et al. (2015), auxin promotes cell division, tissue differentiation, and assimilate distribution, ultimately improving photosynthesis and biomass accumulation.

The highest porang tuber weight was obtained at 50 ppm treatment (33,95 g), which was significantly different from other treatments. Based on spraying frequency, at early nursery produced the highest tuber weight (20,49 g). A significant interaction between 100 ppm treatment and at early nursery resulted in the highest tuber weight of 42,49 g. NAA application promotes cell development and accelerates growth, leading to increased tuber enlargement. Auxin plays an important role in regulating cell development and plant hormonal activity, thereby enhancing yield. Fresh weight reflects metabolic accumulation; thus, higher growth rates result in greater biomass.

NAA also improves root formation, which supports nutrient uptake for tuber development. Duan et al. (2023) reported similar results in sweet potato, where NAA increased tuber growth through improved root development. However, excessive auxin concentrations can reduce fresh weight due to leaf abscission (Nikmah et al., 2017). Early auxin application contributes to increased tuber weight by enhancing cell growth, improving water and nutrient uptake, and reducing physiological stress. Although spraying frequency did not significantly affect tuber weight, early nursery helped plants adapt to environmental stress, accelerated tissue formation, and improved root development, ultimately supporting tuber growth on sweet potato (Duan et al., 2023).

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Chlorophyll a, b, Total, and Stomatal Density

The results of the analysis showed that NAA auxin concentration, application frequency, and the interaction between the two factors did not have a significant effect on chlorophyll a, chlorophyll b, total chlorophyll, and stomatal density. The mean data for chlorophyll a, chlorophyll b, total chlorophyll, and stomatal density under treatments of NAA auxin concentration and frequency are presented in Table 6.

Table 6. Chlorophyll a, b, total, and Stomatal Density Under Treatments of NAA Auxin Concentration and Application Frequency on Porang at 10 Weeks After Transplanting (WAT)

Concentration on NAA	Chlorophyll a	Chlorophyll b	Chlorophyll total	Stomata Density
	……………………mg/g ……………………			
Control (A0)	2810.49	2814.90	5617.65	97.66
50 ppm (A1)	2969.91	3132.22	6093.67	112.10
100 ppm (A2)	2879.94	3352.42	6223.60	114.65
150 ppm (A3)	2908.54	2627.52	5528.55	105.31
Frequency on NAA				
At the Beginning of nursery (P1)	2952.60	3151.05	6095.18	112.10
At the beginning of nursery and 7 days after sowing (P2)	2831.84	2812.48	5636.56	102.76
Interaction	tn	tn	tn	tn

Note: Values followed by different letters for each different treatment indicate a significant difference based on Duncan's Multiple Range Test at the 5% level.

Stomata are closely related to chloroplasts in the guard cells. An increase in the number of chloroplasts can improve stomatal function in absorbing CO_2 for photosynthesis. An ideal number and density of stomata support smooth plant metabolism. An NAA concentration of 100 ppm can increase the levels of chlorophyll a, chlorophyll b, total chlorophyll, and the number of stomata. NAA helps increase stomatal number, chlorophyll synthesis, photosynthetic pigments, and the rate of photosynthesis (Raoofi et al., 2014).

The increase in chlorophyll content is believed to be related to the ability of NAA to utilize sunlight to convert photochemical energy into biochemical energy, which in turn enhances assimilation and synthesis efficiency. Auxin, including NAA, plays an important role in regulating plant growth and development and in increasing the concentrations of chlorophyll a and b (Guo et al., 2018). In addition, NAA improves the efficiency of light energy capture at the reaction centers of Photosystem II, increases the openness of reaction centers, and enhances effective quantum yield, thereby supporting photosynthesis by producing more ATP and NADPH (Martins et al., 2018).

Auxin also affects plant capacity by regulating the formation of stomata and leaf veins. Excessively high auxin levels can reduce stomatal numbers, whereas disturbances in auxin biosynthesis or signaling can cause stomatal clustering (Zhang et al., 2014).

CONCLUSION

NAA auxin concentration significantly affected the growth of porang tuber cuttings, where a concentration of 100 ppm enhanced shoot growth, vegetative development, and both fresh and dry weights of the plants. In contrast, the frequency of NAA application did not show a significant effect on all observed parameters; however, spraying at the beginning of the nursery stage produced the best results for plant height, tuber weight, chlorophyll a, chlorophyll b, and total chlorophyll, while spraying at the beginning of the nursery and again at 7 days after sowing resulted in higher numbers of shoots and leaves, greater stem diameter, longer roots, and increased fresh and dry weights of both roots and shoots. Furthermore, the interaction between NAA concentration and application frequency significantly influenced the number of leaves at 3 weeks after transplanting and tuber weight, with the combination of 100 ppm NAA and spraying at the beginning of the nursery stage producing the best overall results.

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