# *INDOLE BUTIRAT ACID* (IBA) INDUCES HIGH FREQUENCY MULTIPLICATION IN ENDANGERED TITAN ARUM (*Amorphophallus titanum* (Becc.)): AN APPROACH TO GERMPLASM CONSERVATION

Ryan Budi Setiawan*, Nalwida Rozen, and Indah Purnama Sari

Departement of Agronomy, Faculty of Agriculture, Andalas University, Padang, West Sumatra, 25163, Indonesia

Received: 26 March 2024 , Revised: 1 October 2024, Accepted: 4 February 2025

*INDOLE BUTIRAT ACID* (IBA) INDUCES HIGH FREQUENCY MULTIPLICATION IN ENDANGERED TITAN ARUM (*Amorphophallus titanum* (Becc.)): APPROACH TO GERMPLASM CONSERVATION. Titan arum (*Amorphophallus titanum* (Becc.)) was an endemic flora found only on the island of Sumatra, listed as endangered and possessing the largest flower among 170 species of *Amorphophallus*. Conservation activities could benefit from the use of plant propagation through cuttings. The success of cuttings was determined by the concentration of plant growth regulators (PGR) to induce the formation of roots, corms, and shoots, making the study of PGR concentration important. This study aimed to find the best IBA concentration to induce roots, corms, and shoots in *A. titanum*. The research was conducted from February to October 2023. The study was designed based on a completely randomized design with treatments of IBA concentration consisting of 5 levels: 0, 5, 10, 15, and 20 mg L-1. The results showed that an IBA concentration of 15 mg L-1 produced the best survival percentage (100%), rooting percentage (93.33%), corm formation percentage (93.33%), shoot formation percentage (76.67%), and an average of 1.20 shoots per cutting on *A. titanum* petiole cuttings.

Keywords: Biodiversity, conservation, endemic, extinct, plant growth regulator

*INDOLE BUTIRAT ACID (IBA) MENDORONG LAJU MULTIPLIKASI YANG TINGGI PADA BUNGA BANGKAI (*Amorphophallus titanum *(Becc.)): PENDEKATAN UNTUK KONSERVASI PLASMA NUTFAH. Bunga bangkai (*Amorphophallus titanum *(Becc.)) adalah flora endemik yang hanya ditemukan di pulau Sumatera. Tumbuhan ini terdaftar sebagai terancam punah dan memiliki bunga terbesar di antara 170 spesies* Amorphophallus*. Perbanyakan tanaman melalui stek dapat digunakan untuk mendukung kegiatan konservasi. Keberhasilan stek ditentukan oleh konsentrasi zat pengatur tumbuh (ZPT) untuk merangsang pembentukan akar, umbi, dan tunas, sehingga studi mengenai konsentrasi ZPT menjadi penting. Penelitian ini bertujuan untuk mendapatkan konsentrasi IBA terbaik untuk merangsang pembentukan akar, corm, dan tunas pada* A. titanum*. Penelitian ini dilakukan dari bulan Februari hingga Oktober 2023. Penelitian dirancang berdasarkan rancangan acak lengkap dengan perlakuan konsentrasi IBA yang terdiri dari 5 taraf: 0, 5, 10, 15, dan 20 mg L-1. Hasil penelitian menunjukkan bahwa konsentrasi IBA sebesar 15 mg L-1 menghasilkan persentase hidup terbaik (100%), persentase berakar (93,33%), persentase pembentukan corm (93,33%), persentase bertunas (76,67%), dan rata-rata jumlah tunas sebanyak 1.2 tunas pada stek petiole* A. titanum.

*Kata kunci: Biodiversitas, endemic, konservasi, punah, zat pengatur tumbuh*

*Corresponding author: ryan@agr.unand.ac.id

 

## I. INTRODUCTION

A recent report indicated that Indonesia ranked 8th in plant diversity with 19.232 species (World Rain Forest, 2023). One of Indonesia's endemic flora, the Titan arum (*Amorphophallus titanum* (Becc.)), was found only on the Sumatra islands and listed as endangered. *A. titanum* also possessed the largest flower among 170 species of *Amorphophallus* and other flowering plants worldwide (IUCN Redlist, 2024). The flower height ranged from 179.7 cm (Latifah et al., 2015) to 274 cm (Lobin et al., 2007). Despite its great potential, the uses of *A. titanum* are still largely unexplored, unlike species such as *Amorphophallus konjac*, *Amorphophallus muelleri*, and *Amorphophallus paeoniifolius*. For instance, people have used the tuber's glucomannan content to produce food and medicine (Tester & Al Shazzewi, 2016; Choi et al., 2020).

The Government Regulation Number 7 of 1999 and the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.92/MENLHK/SETJEN/KUM.1/8/2018 (KLHK, 2018) both protect *A. titanum*. Various factors such as habitat destruction or deforestation, mistaken tuber exploitation for porang (*A. muelleri*), long reproductive times, and pollination failure due to the protogynous nature of the flower caused the population decline (Korotkova & Barthlott, 2009; Sudarmono et al., 2016; Yudaputa et al., 2021).

In-situ and ex-situ conservation programs are crucial to preserving *A. titanum*. Researchers have conducted several studies to develop propagation methods, such as seed germination (Latifah & Purwantoro, 2015), shoot induction from peculiar callus (Yuzammi et al., 2018), and in vitro culture (Irawati et al., 2017). However, these propagation methods had their drawbacks; propagation using seeds heavily depended on the success of natural cross-pollination, shoot induction from peculiar callus was only effective on mature petiole cuttings, and in vitro culture required standardized procedures to regenerate callus into plantlets.

Therefore, vegetative propagation using petiole cuttings has become a viable and quick solution for *A. titanum*'s conservation efforts. The advantage of using cuttings was that the parent plant would remain alive, and its tuber would produce new shoots. However, the success of cuttings was highly dependent on the emergence of roots at the cut site. Several studies on using plant growth regulators (PGR) on cuttings have been conducted on various Amorphophallus genera. According to Aryadi (2004), the use of Rootone F, which contained auxin, was only successful in *A. paeoniifolius* and *A. muelleri* but not in *A. titanum*. Cahyaningsih and Siregar (2013) reported that soaking rachis cuttings of *A. paeoniifolius* in 1 mg $L^{-1}$6-*Benzyl Amino Purine* (BAP) and 1 mg $L^{-1}$*naphthalene Acetic Acid* (NAA) did not give optimal results. Furthermore, Yuzammi and Handayani (2019) also reported that 20 mg $L^{-1}$ NAA induced roots on rachis cuttings of A. paeoniifolius.

One of the plant growth regulators frequently used to stimulate root growth is *Indole Butyric Acid* (IBA). Studies have reported that IBA is the most effective hormone for plant propagation through cuttings, as it has better stability and consistently stimulates root induction and formation in various plant species compared to *Indole Acetic Acid* (IAA) and NAA. In *Solanum procumbens*, using IBA is more effective than NAA and IBA (Tien et al., 2021). Prasad et al. (2022) stated that IBA is more effective in inducing rooting than IAA in *Nerium oleander* plants. The same effect is observed in *Chrysanthemum indicum* cuttings (Ghimire et al., 2022).

Various research has demonstrated the successful use of IBA at concentrations ranging from low to high on different plant species. Sabatino et al. (2013) found that 3000 mg L-1IBA produced the best rooting percentage, number of roots, root length, and shoot height in *Nerium oleander* cuttings. Ningsih et al. (2014) reported that 20 mg $L^{-1}$ IBA produced the highest number of roots in *Nepenthes bicalcarata* Hooker cuttings, but increasing the concentration led to a decrease in the number of roots. The application of 500 mg $L^{-1}$ IBA positively affected the rooting percentage, number of roots, and root length in blueberry (*Vaccinium* spp.) cuttings (Koyama et al., 2019). Abdel-Rahman et al. (2020) also reported that 100 mg L-1 IBA was the best treatment for root induction of *Conocarpus erectus* L. cuttings. Similarly, IBA had a better effect at the same concentration than IAA on *Morus alba* cuttings (Chen et al., 2023). Additionally, 150 mg $L^{-1}$ IBA was the best concentration on *Rhododenderon micranthum* cutting (Oh et al., 2023). These studies show that IBA is effective in stimulating root and shoot formation, enhancing vegetative growth, and improving plant survival rates. Each plant species responds differently to IBA concentrations, making it essential to conduct proper testing to determine the optimal concentration for specific species.

Information about the optimum concentration of IBA to stimulate root, corm, and shoot formation in *A. titanum* is still limited. Recent studies have reported that 15 mg $L^{-1}$ IBA is the best concentration to induce root and corm formation in *A. titanum*. However, this research has not successfully produced shoots or seedlings of *A. titanum*. Therefore, further studies on vegetative propagation are still needed (Setiawan et al., 2023). Underscoring the critical need for research on IBA to support future conservation efforts. The research aimed to develop a multiplication method for *A. titanum* through cutting. Multiplication is a plant propagation technique using segments of the parent plant to get a seedling. In this study, various concentrations of IBA were used to induce the growth of roots, corms, and shoots on the petiole cuttings. The use of IBA was expected to accelerate and improve the success of rooting, corm formation, and shoot development, thus supporting the conservation and preservation efforts. This method aimed not only to increase the number of *A. titanum* but also to maintain genetic diversity and ensure the survival of this species in its natural habitat and other conservation centers. The results of this research are expected to contribute significantly to the conservation efforts of the *A. titanum*.

## II. MATERIAL AND METHOD

### A. Study Site/Location and/or materials

The research was conducted from February to October 2023 in the greenhouse of the Faculty of Agriculture, Universitas Andalas. The tools used included pots, hand sprayers, sterile knives, measuring cups, Erlenmeyer flasks, micropipettes, plastic covers, labels, rulers, measuring tapes, threads, and a camera. The materials used consisted of *A. titanum* petiole cutting from seedlings acclimatized in the Tissue Culture Laboratory, Faculty of Agriculture, Universitas Andalas. This seedling is approximately 8 months old, characterized by healthy seedlings, fresh green leaves, a petiole height of 30-40 cm and diameter of 1-1.5 cm (Figure 1a), IBA, distilled water, rice husk charcoal and sphagnum moss (1:1 v/v) as the planting medium.

### B. Methods

The research was designed as a completely randomized design (CRD) with the treatment of IBA concentrations consisting of five levels: 0, 5, 10, 15, and 20 mg $L^{-1}$. Each treatment level was repeated three times, resulting in a total of 15 experimental units, each consisting of 10 cuttings. Petioles were cut using a sterile knife to a length of about 15 cm with a 45-degree angled cut. The cuttings were soaked in the IBA solution for 20 minutes with a soaking depth of 2 cm.

After soaking, the cuttings were planted in a mixture of sphagnum moss and rice husk charcoal in a 1:1 ratio (v/v), then covered and incubated for 12 weeks in the greenhouse. The observed variables included the survival percentage of cuttings, corm induction percentage, rooting percentage, sprouting percentage, number of roots, root length, shoot height, number of shoots, leaf length, and leaf width. Observations for all variables were conducted in the last week of the study.

## C. Analysis

The observation data were statistically analyzed using analysis of variance (ANOVA) at a significance level of less than 5%. Posthoc test was conducted using the Duncan Multiple Range Test (DMRT) if the p-value (probability) was less than 0.05. Data analysis was performed using the Statistical Tool for Agricultural Research (STAR) software.

# III. RESULTS AND DISCUSSION

### *Survival Percentage of Cuttings, Corm Induction Percentage, and Rooting Percentage*

Soaking the petioles of A. titanum in an IBA solution affected the survival percentage of cuttings, corm induction percentage, and rooting percentage. The 15 mg $L^{-1}$ IBA treatment was the best result, providing the highest survival percentage (100%), corm induction percentage (93.33%), and rooting percentage (93.33%) compared to all other treatments (Table 1).

The surviving cuttings were characterized by green color, corm formation, root development, and firmness without rotting. In contrast, the dead cuttings were identified by a color change to yellowish-brown, softening, rotting, shriveling, cracking at the cut ends, and drying out. These results were better than those reported by Yuzammi and Handayani (2019), who found that rachis cuttings of suweg (*A. paeoniifolius*) had a survival percentage of 80.00% with the application of NAA up to 30 ppm. Corm induction begins with the swelling of the wounded part of the cutting. This swollen section forms a cluster of undifferentiated cells, known as callus, which is white. The callus then enlarges and forms a corm, which, in further processes, will develop roots (Liu et al., 2014).

Plant regeneration that begins with root induction formed from wounds or stress on the planting material is also known as De novo root regeneration (DNRR) (Steffens & Rasmussen, 2016). The morphogenesis process of petiole cuttings progresses through a critical stage in the eighth week after planting, characterized by forming a corm (Figure 1b). During this phase, the initial petiole gradually shrinks, dries out, and eventually disappears (Figure 1c), leaving a corm with a diameter of 1–2 cm (Figure 1d). This corm functions as a primary storage organ, facilitating subsequent growth stages. New shoots and roots emerge from the corm, marking the initiation of vegetative development (Figure 1e). The formation of the corm represents a pivotal stage in the vegetative propagation of *A. titanum*, as it serves as a storage organ for photosynthates and acts as the foundation for root and shoot development. Observing the percentage of corm formation is crucial, as it marks the initial stage of plant establishment. The corm is irregularly round, with a brown on the outside and white to yellowish-orange on the inside, highlighting its role in storing energy reserves necessary for regeneration and growth. Wulandari et al. (2013) reported that IBA could stimulate and assist cells in differentiating to form roots. Hardjo et al. (2023) reported that auxin can stimulate root formation in *A. muelleri*. Agustiansyah et al. (2014) also reported that increasing IBA concentration positively

Table 1. Survival percentage, corm induction percentage, and rooting percentage of cuttings at 12 weeks after planting

| IBA Consentration (mg $L^{-1}$) | Survival percentage (%) | Corm induction percentage (%) | Rooting percentage (%) |
|---|---|---|---|
| 0 | 50.00 ±20.0 c | 40.00±20.8 b | 33.33± 15.3 b |
| 5 | 96.67± 5.6 ab | 96.67±46.2 a | 93.33± 5.8 a |
| 10 | 60.00± 20.8 bc | 60.00± 10.0 ab | 53.33± 25.2 b |
| 15 | 100.00± 0.0 a | 93.33± 5.6 a | 93.33± 11.5 a |
| 20 | 60.00± 36.0 bc | 60.00±20.0 ab | 53.33± 32.1 b |

*Note: Numbers followed by the same lowercase letters in different columns are not significantly different based on the 5% DMRT test.*

correlates with the percentage of root formation in rose apple (*Syzygium malaccense* (L.) Merr & Perry).

Several studies have reported that the expression of endogenous hormones and nutrient allocation in cuttings are influenced by exogenous auxin. Chen et al. (2023) found that the application of exogenous auxin (ABT-1) can increase endogenous IAA levels and affect the formation of adventitious roots. Besides cell division, cell elongation also occurs when endogenous IBA levels increase (Shang et al., 2021). Furthermore, it is known that auxin can influence endogenous ABA levels, a growth-inhibiting hormone. ABA levels increase during the preparation of root primordia formation and then decrease during the differentiation process of root primordia and root formation (Liu et al., 2021).

Roots not only function in water and nutrient absorption but also support the plant's structure, store photosynthates, and synthesize cytokinin hormones, which play a role in cell division and differentiation, vascular tissue development, and root morphogenesis (Papon & Caurdavault, 2022). Cytokinin is known to stimulate the Cytokinin response regulator (RRs) genes, which are key transcription factors playing a crucial role in root morphogenesis. More than 25 RR proteins are responsible for this process (Zhang et al., 2022).

### *Root Length and Number of Roots*

Observations of root length and the number of roots were conducted at the end of the study. The use of IBA affected the number of roots but not the root length. The root length of *A. titanum* across all IBA concentrations ranged from 5.33 cm to 8.03 cm. The best treatment was the 10 mg $L^{-1}$ IBA concentration, resulting in the highest number of roots, averaging 9.27 per cutting (Table 2). The data indicate that an increase in the number of roots tends to produce shorter roots, except in the treatment without IBA.

The root induction process comprises four stages: priming, initiation, root pattern formation, and root emergence (Yu et al., 2017). Several studies have reported the successful use of IBA in various plant species. According to Yeshiwas et al. (2015), applying 1.000 mg $L^{-1}$ IBA significantly impacted the number and length of roots in rose stem cuttings. Erdiansyah et al. (2016) reported that 4.500 mg $L^{-1}$ IBA applied to Liberica coffee (*Coffea liberica* W. Bull Ex. Hier) resulted in roots 4.97 cm long. Similarly, 4.000 mg $L^{-1}$ IBA produced the longest roots (4.85 cm) in tea (*Camellia sinensis* L.) (Hoque, 2016). Applying 100 mg $L^{-1}$ IBA also produced the longest roots (26.25 cm) and the highest number of roots (6.7) in mulberry cuttings (Sourati et al., 2022). Additionally, 500 mg $L^{-1}$ IBA produced the longest roots (39.5 cm) in Epipremnum aureum stem cuttings (Attanayake et al., 2023). These varied studies show that the effectiveness of IBA concentrations is highly species-dependent.

IBA stimulates the expression of many genes involved in root induction. For example, wounding the plant increases the expression level of the VvPRP gene, which plays a crucial role in altering the mechanical properties of the cell wall, allowing root emergence (Thomas et al., 2003). Optimal concentrations of IBA significantly influence cell metabolism, affecting both molecular and morphological

Table 2. Root length and number of roots at 12 weeks after planting

| IBA Concentration(mg $L^{-1}$) | Root length (cm) | Number of roots |
|---|---|---|
| 0 | 4.23± 1.7 | 3.58 ± 0.4 b |
| 5 | 8.03± 1.6 | 4.80 ± 2.3 b |
| 10 | 5.33± 0.6 | 9.27 ± 2.0 a |
| 15 | 6.91± 1.6 | 4.93 ± 0.2 b |
| 20 | 6.65± 2.6 | 5.47 ± 0.5 b |

*Note: Numbers followed by the same lowercase letters in different columns are not significantly different based on the 5% DMRT test.*

aspects. At the molecular level, IBA regulates the expression of genes associated with root formation. For instance, the PINHEAD/ZWILLE gene governs auxin transport and the formation of root meristems (Brinker et al., 2004), while the MtWOX5 gene plays a key role in the development of adventitious roots (Chen et al., 2009). Furthermore, there is an increased expression of several genes involved in IAA biosynthesis and adventitious root induction, including IAA-efflux (PIN1), IAA-influx (AUX1/LAX3), ASA1 (ATHRANILATE SYNTHASE-alpha1), and ANTHRANILATE SYNTHASE-beta1 (ASB1) (Fattorini et al., 2017). The miR156 gene also contributes to adventitious root formation (Ye et al., 2020).

### *Percentage of Shoots, Number of Shoots, and Shoot Height*

The IBA concentration did not influence the percentage of shoots, number of shoots, and shoot height. The percentage of shoots ranged from 76.67% to 23.33%, the number of shoots ranged from 1.07 to 1.33, and the shoot height ranged from 5.12 cm to 17.37 cm (Table 3). Lower concentrations of IBA appeared to promote taller shoot growth compared to other treatments. In *A. titanum*, the shoot is essentially a petiole organ that grows like a stem, also referred to as a pseudostem.

The shoot initiation process begins with the division and differentiation of meristem cells in the corm. Initially, the emerging shoot buds are white and eventually turn green as they continue to grow, forming the petiole, rachis, and leaf blades (Figure 1f). The formation of shoots is known to be triggered by cytokinins synthesized in the roots. Several studies have reported that cytokinins act as transcription factors that stimulate genes involved in the division and differentiation of meristem cells. For example, the Wuschel gene expressed in the promeristem stimulates cell differentiation during shoot formation (Yadav et al., 2011). Liu et al. (2018) also reported that the AHK4 and CYCD genes are highly expressed in meristem tissues during cell division.

The optimum IBA concentration significantly influences plant metabolism, impacting both molecular and morphological aspects in the formation of shoots. Optimal auxin levels stimulate shoot growth, as reported by Müller and Leyser (2011) reported that auxin plays a crucial role in the cell elongation process by affecting the synthesis of structural proteins that contribute to cell wall development and regulate elongation at the shoot tip. Additionally, endogenous cytokinins synthesized in the shoots are vital, as they interact with auxins in shoot formation. Cytokinins also play a critical role in cell wall formation during shoot development, activating the expression of the *Tumorous Shoot Development* (TSD1) gene and the Korrigan1 gene, which produce the *Endo-1,4-β-D-glucanase protein* necessary for cellulose synthesis in cell wall formation (Frank et al., 2002; Krupkova & Schmulling, 2009). Furthermore, the enhanced expression of the TSD2 gene, which encodes *S-adenosyl-L-Met–dependent methyltransferase*, contributes to pectin biosynthesis during cell wall construction and organ formation (Frank et al., 2002; Krupková et al., 2007). Cytokinins are also known to influence cell proliferation, endoreduplication, and mitosis by controlling

Table 3. Shoots percentage, number of shoots, and shoot height at 12 weeks after planting

| IBA consentration (mg $L^{-1}$) | Shoots percentage (%) | Number of shoots | Shoot height (cm) |
|---|---|---|---|
| 0 | 23.33± 5.6 | 1.11± 0.2 | 7.86± 7.5 |
| 5 | 50.00± 30.0 | 1.07± 0.1 | 17.37± 2.5 |
| 10 | 50.00± 10.0 | 1.33± 0.4 | 5.12± 2.1 |
| 15 | 76.67± 26.6 | 1.20± 0.2 | 12.47± 11.3 |
| 20 | 43.33± 30.3 | 1.22± 0.2 | 7.50± 7.5 |

Description: Data are not significantly different based on the F-test at the 5% level.

the transitions from the G1 (Gap1) phase to the S (Synthesis) phase and from the G2 (Gap2) phase to the M (Mitosis) phase, involving Cyclin-dependent kinases (CDKs) and cyclins as subunits. Additionally, cytokinins stimulate shoot initiation by regulating proliferation in the Shoot Apical Meristem (SAM) (Schaller et al., 2014).

### *The length and width of leaves*

The length and width of leaves were not significantly influenced by the concentration of IBA applied. The leaf length ranged from 4.58 cm to 6.92 cm, while the leaf width ranged from 1.35 cm to 4.80 cm (Table 4). Although there was no significant effect, the 10 mg $L^{-1}$ IBA generally produced the longest leaves (6.32 cm) and the widest leaves (4.80 cm).

The increase in leaf size is related to the increase in the number and length of roots, which allows for the optimal absorption of nutrients and water. Karam et al. (2022) reported that rice husk charcoal contains several nutrients such as: carbon, nitrogen, silica, dan iron. Furthermore, charcoal improves to medium physical structure and various other positive attributes. Besides, charcoal is a carbon-rich, porous substance with multiple functional groups that can potentially increase nutrient retention. Additionally, Sphagnum moss possesses unique characteristics such as controlling the pH of its environment, water remediation, and gas exchange, making it an excellent sustainable replacement. Sphagnum moss is home to a unique microbiome, including endophytic growth-promoting bacteria and fungi such as *Pseudomonas*, *Serratia*, *Burkholderia*, *Flavobacterium* and *Collimonas* (McKeon-Bennett & Hodkinson, 2021)

Several macro-nutrients play central roles in plant metabolism: Nitrogen is essential for synthesizing proteins, nucleic acids, chlorophyll, coenzymes, phytohormones, and secondary metabolites (Kusano et al., 2011). Sulfur is assimilated into amino acids such as cysteine, which are used for synthesizing enzymes and coenzymes (Kopriva et al., 2019). Phosphorus: This element is a structural component of

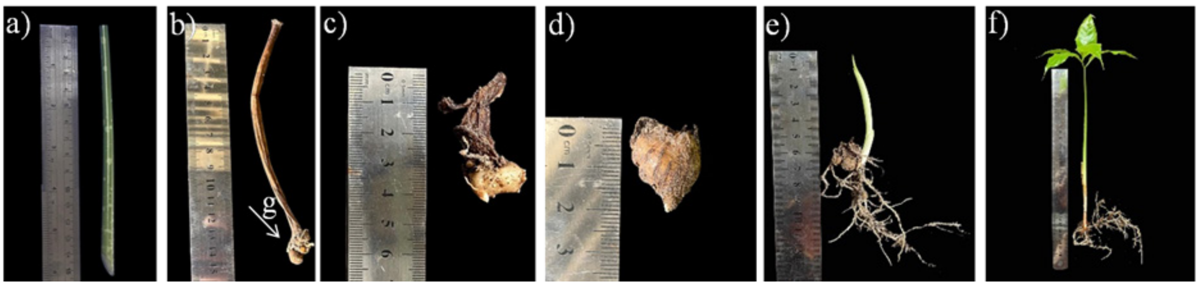


Figure 1. Morphogenesis of *A. titanum* from petiole cuttings.a) petiole cutting as planting material b) petiole begins to shrink at 4 weeks, c) petiole gradually disappears at 6 weeks, d) corm induction observed at 8 weeks, e) shoot formation at 10 weeks, f) seedling development after 12 weeks, g) initiation site visible at 4 weeks

Table 4. Length and width of leaves at 12 weeks after planting

| IBA consentration (mg $L^{-1}$) | Leaf length (cm) | Leaf width (cm) |
|---|---|---|
| 0 | 4.60± 2.0 | 1.35± 0.8 |
| 5 | 6.92± 0.7 | 2.25± 0.3 |
| 10 | 6.32± 1.1 | 4.80± 3.3 |
| 15 | 4.58± 4.1 | 2.11± 0.6 |
| 20 | 5.67± 3.8 | 2.58± 0.5 |

*Note: Data are not significantly different based on the F-test at the 5% level.*

nucleic acids and plays a crucial role in energy transfer as a component of adenosine phosphate and in the transfer of carbohydrates between organelles in leaf cells (Malhotra et al., 2019). Magnesium is a component of chlorophyll and is necessary for photosynthesis, the transport of photoassimilates, and protein synthesis (Kwon et al., 2019).Calcium is important for cell wall stabilization and the regulation of osmotic pressure. Potassium regulates osmotic pressure, which is vital for cell expansion, stomatal movement, sucrose translocation, and the rate of water movement driven by mass flow within the plant (Hawkesford et al., 2023).

Furthermore, leaves are sources of endogenous auxin and carbohydrates, which are considered the main energy sources during root formation. Auxin and carbohydrates are translocated from the leaves to the basal wound site on the cuttings, where further interaction between endogenous and exogenous auxin occurs to initiate root primordia formation. Therefore, an increase in the number of leaves will enhance the root number and vice versa (Nasri et al., 2015).

### *Correlation Analysis*

Correlation analysis plays a crucial role in identifying and quantifying the relationships between variables. It helps to understand the strength and direction of these relationships, which can inform hypothesis testing. The correlation analysis of various variables related to the cuttings of *A. titanum* reveals insightful relationships among the variables. The survival percentage shows a very strong positive correlation with the rooting percentage at 0.98, indicating that higher survival rates are closely associated with successful root development. Similarly, survival correlates well with the shoot percentage (0.89), suggesting increased survival rates promote shoot growth.

Root length also demonstrates significant positive correlations with both survival percentage (0.93) and rooting percentage (0.88), further emphasizing the importance of root development in overall plant health. However, corm induction percentage shows weaker correlations with other variables, particularly with root length (0.05), indicating that corm induction may operate independently from root growth parameters. Interestingly, the number of roots has a negligible correlation with survival percentage (0.06), suggesting that merely having more roots does not necessarily translate to better survival outcomes. In contrast, the number of shoots has a strong positive correlation with number of roots (0.87), indicating that increased root numbers may support shoot development.

The correlation between shoot height and other parameters is noteworthy; it correlates positively with survival percentage (0.74) and root length (0.79), indicating that taller shoots

Table 5. Correlation analysis of several variable on morphological traits of *A. titanum*

| Variable | SP | RP | SHP | CIP | RL | NR | NS | SH | LL | LW |
|---|---|---|---|---|---|---|---|---|---|---|
| SP | 1.00 | | | | | | | | | |
| RP | 0.98 | 1.00 | | | | | | | | |
| SHP | 0.89 | 0.84 | 1.00 | | | | | | | |
| CIP | 0.36 | 0.47 | 0.62 | 1.00 | | | | | | |
| RL | 0.93 | 0.88 | 0.73 | 0.05 | 1.00 | | | | | |
| NR | 0.06 | -0.08 | 0.23 | 0.01 | -0.10 | 1.00 | | | | |
| NS | -0.11 | -0.24 | 0.26 | 0.22 | -0.28 | 0.87 | 1.00 | | | |
| SH | 0.74 | 0.83 | 0.41 | 0.13 | 0.79 | -0.49 | -0.73 | 1.00 | | |
| LL | 0.40 | 0.28 | 0.12 | -0.54 | 0.50 | 0.48 | 0.03 | 0.28 | 1.00 | |
| LW | 0.08 | -0.07 | 0.23 | -0.04 | -0.06 | 0.99 | 0.84 | -0.47 | 0.54 | 1.00 |

Note : SP (survival percentage), RP (rooting percentage), SHP (shoots percentage), CIP (corm induction percentage), RL (roots length), NR (number of roots), NS (number of shoots), SH (shoots height), LL (leaf length), LW (leaf width) are associated with better survival and root lengths. Leaf length shows a more complex relationship, as it correlates positively with root length (0.50) but negatively with corm induction percentage (-0.54), suggesting potential competition for resources during the growth phase. Finally, leaf width has a strong positive correlation with number of roots (0.99) and number of shoots (0.84), suggesting that wider leaves are associated with a higher number of roots and shoots, which may enhance overall plant vigor. This comprehensive correlation analysis highlights the interdependence of these variables in the propagation of *A. titanum*, providing valuable insights for future research and conservation efforts.

Among the variables assessed, the shoot percentage and the number of shoots are the most critical criteria for evaluating the success of cutting and propagation. These two parameters directly reflect the plant's ability to regenerate and establish new growth from the cutting, making them essential indicators of successful vegetative propagation. While other variables, such as survival percentage, rooting percentage, and corm induction percentage, are also important, the percentage of shoot formation and the number of shoots provide the most reliable measure of the effectiveness of the propagation process. Thus, these parameters are the most important to monitor for successful propagation.

## IV. CONCLUSION

Based on the research, the propagation of *A. titanum* through multiplication using petiole cuttings with various concentrations of IBA has been successfully demonstrated. Among these, 15 mg $L^{-1}$ IBA emerged as the optimal concentration for shoot multiplication that achieved remarkable results: a 100% survival rate, 93.33% rooting success, 93.33% corm formation, 76.67% shoot formation, and an average of 1.20 shoots per cutting. These outcomes highlight the effectiveness of IBA in enhancing the propagation process, providing valuable insights for the conservation and cultivation efforts of *A. titanum*.

## ACKNOWLEDGEMENT

The author would like to express gratitude to the Faculty of Agriculture and Institute of Research and Community Service (Lembaga Penelitian dan Pengabdian Masyarakat/LPPM) Universitas Andalas for the research funding with contract number 06/PL/SPK/PNP/FAPERTA-Unand/2022 and facilities provided in mentoring at Scopus camp.

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