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The growth performance of *Rhizophora apiculata* using the cut-propagule method for mangrove rehabilitation in Indonesia

ANDI HURUL AUNI USMAN[1], ADISTI PERMATASARI PUTRI HARTOYO[1,2,♥], CECEP KUSMANA[1]
[1]Department of Silviculture, Faculty of Forestry and Environment, Institut Pertanian Bogor. Jl. Ulin, IPB Dramaga Campus, Bogor 16680, West Java, Indonesia. Tel./fax.: +62-251-8621677, ♥email: adistipermatasari@apps.ipb.ac.id
[2]Environmental Research Center, Institut Pertanian Bogor. Jl. Ulin, IPB Dramaga Campus, Bogor 16680, West Java, Indonesia

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Abstract. *Usman AHA, Hartoyo APP, Kusmana C. 2022. The growth performance of* Rhizophora apiculata *using the cut-propagule method for mangrove rehabilitation in Indonesia. Biodiversitas 23: 6366-6378.* A high decrease in the size of Indonesia's mangrove forests requires effective and efficient rehabilitation efforts. One of the efforts is using *Rhizophora apiculata* as the adaptive and fast-growing mangrove species and its cut-propagule seedling method for accelerating plant propagation. The objectives of this study were to analyze the growth performance of *R. apiculata* propagules with various treatments of propagule cutting, seedling media, and giving growth regulators (PGR), as well as to determine the best combination of treatment for the growth of *R. apiculata*. An experimental study was conducted in a greenhouse using a randomized design with 3 factors (propagule cutting, seedling media, and giving PGR) and 3 replications. The interaction of the combination of cut-propagule treatment, planting media, and growth regulator (AxBxC) only had a significant effect on the increase in the number of leaves of *R. apiculata*. Complete propagules and the lower part of cutting propagules with a combination of mud+sand seedling media and 10,000 ppm PGR (a0b1c1 and a2b1c1) resulted in the best value on the growth of *R. apiculata*. The cut-propagule seedling method of *R. apiculata* still showed good growth so it can be used as an alternative to mass vegetative reproduction in mangrove rehabilitation activity.

Keywords: Mangrove, rehabilitation, vegetative reproduction

INTRODUCTION

Mangrove forests have a crucial role in the balance of the ecosystem, both in maintaining the productivity of coastal waters and in supporting the lives of local communities, as well as their role in environmental services. According to Kathiresan (2012), mangrove forests play an essential role in protecting and stabilizing coastal areas, especially in maintaining the quality of the ecosystems of agriculture, fisheries, and settlements in the vicinity through the ecological, economic, and social benefits of mangrove forests.

The condition of Indonesia's mangrove forests shows a decline in line with the times, both qualitative and quantitative. Rahmanto (2020) states that the potential of mangrove resources in Indonesia reaches 3.31 million hectares which are 2.5 million hectares in forest areas and about 777,719.44 hectares outside forest areas with critical mangrove forest areas (rare and very rare canopy density, which is less than 50%) of 637,624.31 hectares (inside and outside the forest area). Mangrove forests with critical conditions describe the condition of mangrove forests that have lost their ecological functions because they are damaged and degraded. One of the efforts to accelerate the recovery of the mangrove ecosystem is through rehabilitation activities. The most important activity in mangrove rehabilitation is the procurement of seeds. In terms of rehabilitation, the seeds needed are significant in quantity (available) and should have adaptability, and are fast-growing species to accelerate rehabilitation programs.

Rhizophora apiculata Blume is a species of the *Rhizophoraceae* family and is one of the most important species in the mangrove forest ecosystem. *R. apiculata* is a fast-growing mangrove with a high adaptation to environmental changes, such as diverse substrate, salinity fluctuations, tides, organic matter content, temperature, and pH. Hence, this species can grow well in almost all mangrove forest zones, from the coastal zone to the riverbank (Amaliyah et al. 2018). However, the time required for growth from flower buds to the availability of ripe *R. apiculata* fruit is approximately 61 weeks (Aluri 2013).

Seed propagation can be an alternative for accelerating the restoration of the mangrove ecosystem through rehabilitation, specifically the propagule-cutting method. This method has been carried out by Kusmana et al. (2018) on the propagule of *Bruguiera gymnorrhiza*. Komiyama et al. (1998) researched cuttings of *R. apiculata* into three parts. Then, they planted them directly in the mangrove field, which was very susceptible to seedling death due to pests (such as crabs) and propagules drifting due to water currents, especially if the propagule has been cut smaller size, the strength to withstand the current was getting smaller.

Based on this background, a study of *Rhizophora apiculata* using the cut-propagule method for mangrove rehabilitation in Indonesia is necessary. *R. apiculata* propagule will be cut into two parts (upper and lower parts) and planted in a homogeneous environmental condition, namely in a greenhouse by adding several combinations of planting media (mud, sand, and compost) and plant growth regulator (PGR) containing the hormones IBA (indole butyric acid) and NAA (naphthalene acetic acid) at various doses to support the growth performance of the cuttings propagules. This method was carried out according to previous research by Kusmana et al. (2018) on *Bruguiera gymnorrhiza* cuttings was done previously. The objectives of this study were i) to analyze the growth performance of *R. apiculata* propagule with various treatments, such as propagule cutting, seedling media, and giving PGR, also ii) to determine the best combination of treatments for the growth performance of *R. apiculata.*

MATERIALS AND METHODS

Study site and period

This research was conducted for 5 months, from May to September 2022, in the greenhouse of the Ecology Division, Department of Silviculture, Faculty of Forestry and Environment, IPB University (Figure 1A). The location for taking propagule was in the Angke Kapuk Mangrove Ecotourism Area (6°07'18.5"S 106°45'18.3"E), North Jakarta. The location is presented in Figure 1B.

Tools and materials

The tools used in this study were plastic buckets, a cutter, a ruler, calipers, an autoclave, digital scales, 70% shade-net, UV transparent plastic, a hand sprayer, bamboo, stationery, a tally sheet, a calculator, and camera. In addition, the materials used were polybag (15 cm x 20 cm), *Rhizophora apiculata* propagules, sand, compost, mud, tap water, and PGR (Rootone F).

Procedures

Nursery preparation

Nursery preparation was done by making seedling beds, shade, and polybags. Shade-net with an intensity of 70% was used, and transparent UV plastic was set up to reduce transpiration. In total, 81 polybags were used.

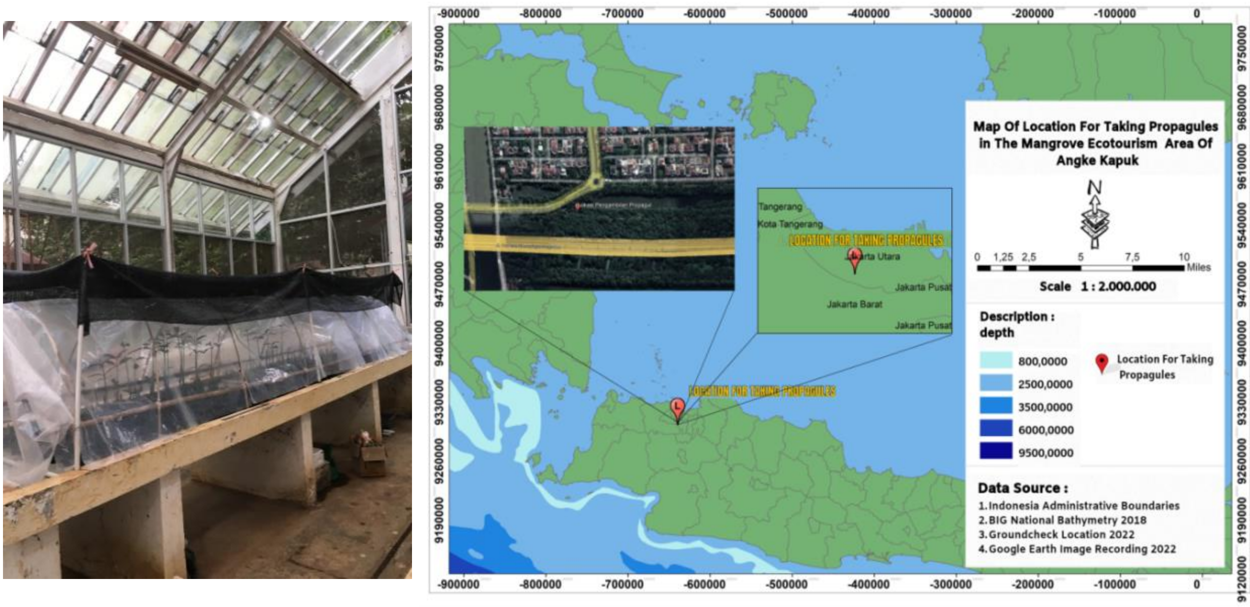
*Plant materials preparation (*R. apiculata*)*

The propagules used were propagules that had fallen from the tree with a length of 20-30 cm and a diameter of 1-2 cm. The seeds used were mature (hypocotyl green in an elongated cylindrical shape, cotyledons appeared and were brownish-red in color), healthy, characterized by no wounds (hypocotyl and plumule parts were not damaged), and pest-free.

Planting media preparation

The planting media used were mud (mangrove mud) taken at the surface of the mud and under the stands of *R. apiculata*, compost (manure compost), and sand. Before the media was put into polybags, the planting media was sterilized. Sterilization of growing media used an autoclave at 121°C for 15 minutes. Then, the sterile growing media was incubated in the open air for a day (24 hours).

Figure 2. Mature propagules of *R. apiculata* that suitable for sowing



A B

Figure 1. A. Nursery location; B. location of propagule collection

Cutting and soaking propagule in PGR

Propagule was treated with three treatments. Those were complete propagule, upper propagule, and lower propagule. First, upper and lower propagules were obtained by cutting obliquely (not horizontally) into two equal lengths to cut at an angle to avoid rotting of the propagule. Second, the propagule was soaked in PGR (0 ppm, 10,000 ppm, and 15,000 ppm). Immersion was carried out for 15 minutes for each treatment.

Planting R. apiculata *propagules*

Each mangrove propagule consisted of three treatments and three replications (Table 1). Hence, the total experimental units were 27 experimental units with 81 cut propagules as experimental units. Moreover, to avoid the high of transpiration, planting was carried out at 15.00-17.00 WIB. Therefore, propagules were planted at a depth of approximately one-third the length of the propagules.

R. apiculata *propagules maintenance*

Plant maintenance activities with 29-31ºC average temperature and 71%-75% average humidity in the greenhouse were carried out by tap water regularly twice a day in the morning at 08.00 WIB and in the afternoon at 16.00 WIB. In addition, weeding was done regularly when the grass started growing to avoid competition for nutrients and sunlight penetration.

Observation and measurement

Observation and measurement research variables were observed and measured directly in the experimental unit for 4 months of observation. The observation period for each parameter is presented in Table 2.

Table 1. Treatment combination

Treatment			Code
Propagule cutting	**Planting media**	**Plant growth regulator (ppm)**	
Complete propagule	Mud	0	a0b0c0
Complete propagule	Mud	10 000	a0b0c1
Complete propagule	Mud	15 000	a0b0c2
Complete propagule	Mud+sand in a 1:1 ratio	0	a0b1c0
Complete propagule	Mud+sand in a 1:1 ratio	10 000	a0b1c1
Complete propagule	Mud+sand in a 1:1 ratio	15 000	a0b1c2
Complete propagule	Mud+sand+compost in a 1:1:1 ratio	0	a0b2c0
Complete propagule	Mud+sand+compost in a 1:1:1 ratio	10 000	a0b2c1
Complete propagule	Mud+sand+compost in a 1:1:1 ratio	15 000	a0b2c2
Upper propagule	Mud	0	a1b0c0
Upper propagule	Mud	10 000	a1b0c1
Upper propagule	Mud	15 000	a1b0c2
Upper propagule	Mud+sand in a 1:1 ratio	0	a1b1c0
Upper propagule	Mud+sand in a 1:1 ratio	10 000	a1b1c1
Upper propagule	Mud+sand in a 1:1 ratio	15 000	a1b1c2
Upper propagule	Mud+sand+compost in a 1:1:1 ratio	0	a1b2c0
Upper propagule	Mud+sand+compost in a 1:1:1 ratio	10 000	a1b2c1
Upper propagule	Mud+sand+compost in a 1:1:1 ratio	15 000	a1b2c2
Lower propagule	Mud	0	a2b0c0
Lower propagule	Mud	10 000	a2b0c1
Lower propagule	Mud	15 000	a2b0c2
Lower propagule	Mud+sand in a 1:1 ratio	0	a2b1c0
Lower propagule	Mud+sand in a 1:1 ratio	10 000	a2b1c1
Lower propagule	Mud+sand in a 1:1 ratio	15 000	a2b1c2
Lower propagule	Mud+sand+compost in a 1:1:1 ratio	0	a2b2c0
Lower propagule	Mud+sand+compost in a 1:1:1 ratio	10 000	a2b2c1
Lower propagule	Mud+sand+compost in a 1:1:1 ratio	15 000	a2b2c2

REPLICATION 1			REPLICATION 2			REPLICATION 3		
A0B0C0	A0B0C1	A0B0C2	A0B0C0	A0B0C1	A0B0C2	A0B0C0	A0B0C1	A0B0C2
A0B1C0	A0B1C1	A0B1C2	A0B1C0	A0B1C1	A0B1C2	A0B1C0	A0B1C1	A0B1C2
A0B2C0	A0B2C1	A0B2C2	A0B2C0	A0B2C1	A0B2C2	A0B2C0	A0B2C1	A0B2C2
A1B0C0	A1B0C1	A1B0C2	A1B0C0	A1B0C1	A1B0C2	A1B0C0	A1B0C1	A1B0C2
A1B1C0	A1B1C1	A1B1C2	A1B1C0	A1B1C1	A1B1C2	A1B1C0	A1B1C1	A1B1C2
A1B2C0	A1B2C1	A1B2C2	A1B2C0	A1B2C1	A1B2C2	A1B2C0	A1B2C1	A1B2C2
A2B0C0	A2B0C1	A2B0C2	A2B0C0	A2B0C1	A2B0C2	A2B0C0	A2B0C1	A2B0C2
A2B1C0	A2B1C1	A2B1C2	A2B1C0	A2B1C1	A2B1C2	A2B1C0	A2B1C1	A2B1C2
A2B2C0	A2B2C1	A2B2C2	A2B2C0	A2B2C1	A2B2C2	A2B2C0	A2B2C1	A2B2C2

Figure 3. Observation design layout

Table 2. The observation period for each parameter

Parameter	Period
Seedling height	Once a week for 4 months
Seedling stem diameter	Once a week for 4 months
Number of leaves	Once a week for 4 months
Number of roots	End of observation
Number of new shoots	Once a week for 4 months
New shoots height	Once a week for 4 months
New shoots diameter	Once a week for 4 months
Fresh weight of biomass	End of observation
Dry weight of biomass	End of observation

Experimental design

The experimental design was carried out using a Factorial Completely Randomized Design (CRD) with 3 factors and 3 replications (Figure 3).

Data analysis

Analysis of data was obtained through several observation variables. The observation variables are described in detail as follows:

The percentage of plant life is obtained using the following formula (Wahyuningtyas et al. 2022):

$$SR = \frac{Tt}{To}\ X\ 100\%$$

Where:

SR (Survival Rate) : percentage of plant life

Tt : number of live plants at the time of observation

To : number of plants when planted

The difference in plant height gain is obtained based on the following formula (Wahyuningtyas et al. 2022):

$$\blacktriangle X = X_2 - X_1$$

Where:

X1 : initial plant height

X2 : plant height at the time of measurement

The difference in the increase in plant diameter is obtained based on the following formula (Wahyuningtyas et al. 2022):

$$\blacktriangle D = d_2 - d_1$$

Where:

d1 : initial plant diameter

d2 : plant diameter at the time of measurement

The Seedling Quality Index is calculated based on the Dickson Quality Index (DQI) formula with the following equation (Kakabouki et al. 2021):

$$DQI = \frac{TDM\ (g)}{\frac{H\ (cm)}{D\ (mm)} + \frac{SDM\ (g)}{RDM\ (g)}}$$

Where:

TDM (Total Dry Matter : total dry weight (root dry weight + stem dry weight)

H (Height) : height of propagule

D (Diameter) : diameter of propagule

SDM (Shoot Dry Mass) : dry weight of the stem

RDM (Root Dry Mass) : root dry weight

Shoot:Root Ratio is obtained based on the following equation (Salisu et al. 2020):

$$SRR = \frac{Shoot\ Dry\ Weight}{Root\ Dry\ Weight}$$

The sturdiness quotient (SQ) is obtained based on the following equation (Kuan-Hung et al. 2019):

$$SQ = \frac{height\ increment\ (cm)}{root\ collar\ diameter\ increment\ (mm)}$$

The research data obtained were processed using the Anova table and calculated using the Statistical Analysis System version 9.1.3. The statistical model used in this research activity is (Kritikos et al. 2019):

$$Yijk = \mu + \alpha i + \beta j + (\alpha\beta)ij + \varepsilon ijk$$

Where:

Yijk : Observation result for factor A level I. factor B level j-th. on the k-th test

μ : General mean

αI : Influence of factor A at level i

βj : Influence of factor B at the j-th level

(αβ)ij: Interaction between A and B at factor A level i. factor B level j

εijk : Experimental error for the i-th level of factor A. j-th level of factor B on k-th test/group

If there is a significant effect of the difference in treatment on the observed variables, then each treatment level is compared using Duncan's test at an error level of 5%. Data processing using Microsoft Office Excel 2010 and SPSS 22 software.

RESULTS AND DISCUSSION

Research status of *Rhizophora apiculata* for mangrove rehabilitation

Rhizophora apiculata is one species commonly used in mangrove rehabilitation activities in several areas in Indonesia, which was later proven by previous researchers and presented in Table 3. This species has morphological characteristics that differ from the others, such as large, above-ground roots. These species were selected for restoration because of their excellent ability to stabilize mud sediments through extensive root systems (Do et al. 2015).

Based on the literature review using VOSviewer and Publish or Perish application, there are 980 articles related to mangrove rehabilitation efforts. Almost 90% of those articles showed utilization of *R. apiculata* as one of the species in the rehabilitation activities. However, only 9-10% are related to mangrove cuttings. The types of mangroves that have been researched on propagule cuttings are *Rhizophora mucronata, R. stylosa, R. apiculata, Bruguiera gymnorrhiza,* and *Kandelia candel*.

Soil properties in the study site

This study site was carried out in Pantai Indah Kapuk (PIK) mangrove ecotourism area. Soil samples were collected to obtain soil fertility status. Soil analysis, soil texture, and water analysis are presented in Tables 4-6.

Soil pH in each combination of planting media used showed a neutral pH value for growth. Each plant requires a specific pH range, but most plants cannot live in acidic soil (pH<4) and alkaline soil (pH> 9) conditions. Soil with low pH (acid) and high pH (alkaline) limits plant growth. It will cause plants to be unable to utilize N, P, K, and other needed nutrients. The low pH also causes the availability of toxic elements such as aluminum which always poisons plants and also binds phosphorus so that it cannot be absorbed by plants (Shivanna and Nagendrappa 2014).

The C-org content indirectly indicates organic matter production at the research site (Blanco-canqui et al. 2013). The combination of planting media B0 and B2 showed a very high C-organic value, while planting media B1 showed a low C-organic value. That was because the combination of planting media B1 had a high sand content which then affected the acquisition of organic matter production in the soil. After all, it was susceptible to nutrient leaching and had a low ability to store and absorb water (Hendawy et al. 2017).

Table 5. Soil texture class

Planting media	3 Fraction texture (%)			Texture class
	Sand	Dust	Clay	
B0	17	27	56	Clay
B1	73	11	16	Sandy loam
B2	75	20	5	Loamy sand

Note: B0: mud, B1: mud+sand, B2: mud+sand+compost

Table 6. Water condition specifications

Salinity (ppt)	pH	Temperature (°C)
3	6.5	28

Table 3. Use of mangrove species for rehabilitation activities in several areas in Indonesia

Type of species	Rehabilitation location	References
Avicennia alba, Rhizophora apiculata, R. mucronata, Sonneratia caseolaris, S. alba, Nypa fruticans	Kotabaru District, South Kalimantan	Kasman and Astuti (2020)
Avicennia officinalis, Avicennia marina, Bruguiera cylindrica, B. gymnorrhiza, B. parviflora, Rhizophora apiculata, R. mucronata. Sonneratia caseolaris	Langsa City, Aceh	Iswahyudi et al. (2019)
Avicennia lanata, Ceriops decandra, Ceriops tagal, Rhizophora apiculata, R. mucronata, R. stylosa, Sonneratia alba	Gerupuk Bay, Central Lombok, South Coast Lombok Island.	Sani et al. (2019)
Rhizophora apiculata, Sonneratia alba	Lantang Peo Village, Tanakeke Island, South Sulawesi	Brown et al. (2014)
R. apiculata, B. sexangula, B. gymnorrhiza, R. mucronata	Pannikiang Island, Barru District, South Sulawesi	Rusdi et al. (2020)

Table 4. Soil analysis test result

Test Parameters		Soil sample		
		B0 (mud)	B1 (mud+sand)	B2 (mud+sand+compost)
pH	H_2O	7.6 (slightly alkaline)	7.6 (slightly alkaline)	7.6 (slightly alkaline)
	N KCl	6.9	6.6	7.2
C Organic (%)		6.67 (very high)	1.94 (low)	7.86 (very high)
N-Total (%)		0.35 (medium)	0.13 (low)	0.41 (medium)
C/N Ratio		19 (high)	15 (medium)	19 (high)
P_2O_5	Available (mg/kg)	125.5 (very high)	59.7 (very high)	497.9 (very high)
	Potential (mg/100g)	223 (very high)	102 (very high)	377 (very high)
K_2O	Available (mg/Kg)	0.9	1.2	1.2
	Potential (mg/100g)	227 (very high)	150 (very high)	232 (very high)
Exchangeable cation	K^+	1.93 (very high)	0.85 (high)	2.14 (very high)
(cmol(+)/kg)	Na^+	2.21 (very high)	0.76 (medium)	1.09 (very high)
	Ca^{2+}	34.80 (very high)	10.86 (medium)	21.67 (very high)
	Mg^{2+}	8.53 (very high)	2.92 (high)	7.63 (high)
Cation exchange capacity	(cmol(+)/kg)	31.46 (high)	13.11 (low)	18.62 (medium)
Alkaline saturation (%)		100 (very high)	100 (very high)	100 (very high)
Exchangeable acidity	Al^{2+}	<0.05	<0.05	<0.05
(cmol(+)/kg)	H^+	0.25	0.17	0.19
Salinity (PPT)		0.60 (very low)	0.24 (very low)	0.40 (very low)

Note: *Tested by PT Biodiversitas Biotechnology Indonesia. ICBB laboratory. *source criteria for soil analysis test results: Eviati and Sulaeman (soil research center) (2009)

Macronutrients that are very important for plants are Nitrogen (N), Phosphorus (P), and Kalium (K). The soil analysis results showed that the element N is low to moderate. N functions in the formation of plant proteins. The amount of soil N depends on environmental conditions such as climate and the type of vegetation (Sharma 2018). Meanwhile, the P and K content in the growing media used showed high to very high values. Phosphorus functions in cell division, albumin formation, flower, fruit, and seed formation, accelerates maturation, and strengthens stems that are not easy to collapse. The cause of high and low potassium is influenced by the parent material and soil pH. Acidic soil pH will cause an increase in potassium fixation, causing a decrease in the availability of K elements in the soil (Das and Bindi 2014).

In addition to nitrogen, phosphorus, and potassium, other critical macronutrients are calcium (Ca), magnesium (Mg), and sodium (Na). The results of the analysis of the chemical properties of the soil showed that the study site had moderate to very high calcium content, high to very high magnesium, and moderate to very high sodium. These nutrients are sufficient to balance soil fertility (Castan et al. 2016).

C/N relates to the rate of humification and mineralization carried out by soil microorganisms. C/N shows whether or not the decomposition of organic matter is good (Wan et al. 2014). The C/N value in the results of the soil analysis tests carried out showed moderate to high results, which can be assumed that the organic matter contained in the planting media can be decomposed properly.

Soinne et al. (2021) stated that soils with high clay content tend to have high water content, organic matter, and CEC (Cation Exchange Capacity). That is because the clay fraction has a large specific surface area to adsorb water molecules or cations. Sandy loam textured soils contain more colloids and can absorb more cations than sandy soil. However, sandy loam soil has a delicate and loose texture; the drainage is not good because in loose soil, there are pore spaces that can be filled by groundwater and air, so the soil has a high holding capacity or water storage capacity. On the other hand, loose soil is very good for plant growth because groundwater and air move smoothly, and the temperature is stable, which can ultimately stimulate the growth of soil microorganisms in the process of weathering organic matter in the soil (Nath 2014). That is because sandy loam soils can hold water and contain greater nutrients (Dou et al. 2016), and the soil conditions are more fertile with more nitrogen and organic matter.

According to Hendawy et al. (2017), sandy soil is sand with a content >70% in moist conditions; sandy soil feels coarse and not sticky in this category sandy soil and sandy loam soil. The texture of the loamy sand soil has a high percentage of sand dominant so that it has macro pores. Soil with a loamy sand texture has low aggregation, so its ability to hold water and nutrients is also low. Soil with a sand texture has many macro pores (large), so it is difficult to hold water. The soil in the mangrove forest has the characteristics of always being wet, containing salt, low oxygen content (an oxy), granular and rich in organic materials. Organic matter in the soil comes from the overhaul of plant remains produced by the mangrove. Mangrove soils also contain fine sediments or sand particles and coarse materials such as coral pieces, shell fragments, eggs, and snails. Generally, mangrove soils are muddy, although they can grow on sand, peat, and rocky soil (Indawan et al. 2017).

In general, a good mangrove growth response is obtained at lower salinity. For example, *Rhizophora* can grow at a salinity of 0.0-30.0 ppt. However, the most optimal salinity level for *Rhizophora* growth is 12.0-30.0 ppt. That happens because mangrove plants are not plants that require salt (salt demand) but plants that are tolerant to salt (salt tolerance) (Kodikara et al. 2018). Furthermore, the pH value supporting mangrove growth on the pH component of water is 6.5-7.2 (Raganas and Magcale-Macandog 2020). Moreover, the optimal temperature range for mangrove photosynthesis is 28-32°C, and temperatures>35°C result in the cessation of the photosynthesis process in leaves (Noor et al. 2015).

The growth performance of Rhizophora apiculata *using the cut-propagule method*

The treatment given can affect the growth of seedlings. The recapitulation of the results of the variance of the effect of propagule cutting, planting media, and PGR on several growth parameters of *R. apiculata* seedlings can be seen in Table 7.

The results of the ANOVA test from *R. apiculata* seedlings for 4 months (Table 7) showed that the propagule-cutting treatment had a very significant effect on all observation parameters, while the planting media did not. The addition of PGR significantly affected the number of leaves and shoot:root ratio and was very significant on the SQ parameter. The combination of propagule cutting treatment, planting media, and PGR (AxBxC) only significantly affected the increase in the number of leaves of *R. apiculata*. Based on the results of the ANOVA test, further Duncan tests were carried out (Table 8).

The results of Duncan's test showed that the treatment with cutting propagules had a significant effect on almost all observation parameters, with the complete propagule treatment showing better performance than the propagules treated with cuttings; however, when compared to the performance between the upper and lower pieces of propagules, the lower propagule (a2) tends to show better results than the upper propagule section (a1). Meanwhile, the planting media did not significantly affect all observation parameters; this is in line with research by Kusmana and Lestari (2021), which provide the same combination of planting media, the tolerant and adaptive properties of *R. apiculata* were the reason why the variation in the planting media did not have a significant effect, besides that, the soil analysis results showed that the three combinations of planting media used were still in the fertile category. In giving PGR, control or C0 showed the best value compared to giving PGR, but when compared between giving PGR at a dose of 10,000 ppm and 15,000 ppm, C1 (10,000 ppm) tended to show a better value than C2 (15,000 ppm).

Table 7. The results of the ANOVA test of each parameter on the growth of *R. apiculata*

Parameter	Propagule cutting (A)	Seedling media (B)	PGR (C)	AxB	AxC	BxC	AxBxC
Seedling height	**	tn	tn	tn	tn	tn	tn
Stem diameter	**	tn	tn	tn	tn	**	tn
Number of new shoots	**	tn	tn	tn	tn	tn	tn
Height of new shoots	**	tn	tn	tn	tn	*	tn
Diameter of new shoots	**	tn	tn	tn	tn	tn	tn
Number of leaves	**	tn	*	tn	**	tn	*
Number of roots	**	tn	tn	tn	tn	tn	tn
BBT	**	tn	tn	tn	tn	**	tn
BKT	**	tn	tn	tn	tn	tn	tn
Shoot:root ratio	**	tn	*	tn	tn	tn	tn
SQ	**	tn	**	tn	*	tn	tn
DQI	**	tn	tn	tn	tn	tn	tn

Note: *Significant, **very significant, AxB: interaction between propagule cutting and planting media, AxC: interaction between propagule cutting and giving PGR, BxC: interaction between planting media and giving PGR, AxBxC: interaction between propagule cutting, planting media, and giving PGR, SQ: Sturdiness quotient, DQI: Dickson quality index, BBT: Total fresh weight, BKT: Total dry weight

Table 8. Recapitulation of the Duncan value of the measured parameters

Parameter	A0	A1	A2	B0	B1	B2	C0	C1	C2
Propagule height	21.84^{a}	12.28^{b}	7.55^{c}	14.14^{a}	13.84^{a}	13.70^{a}	14.70^{a}	13.66^{a}	13.32^{a}
Stem diameter	2.17^{a}	2.03^{ab}	1.75^{b}	2.02^{a}	2.11^{a}	1.83^{a}	1.99^{a}	2.08^{a}	1.88^{a}
Number of new shoots	1.00^{b}	1.00^{b}	1.30^{a}	1.07^{a}	1.11^{a}	1.11^{a}	1.04^{a}	1.15^{a}	1.11^{a}
Height of new shoots	25.36^{a}	11.90^{b}	8.17^{c}	15.75^{a}	13.60^{a}	16.09^{a}	14.34^{a}	14.80^{a}	16.30^{a}
Diameter of new shoots	3.05^{a}	2.73^{a}	1.49^{b}	2.30^{a}	2.33^{a}	2.39^{a}	2.49^{a}	2.15^{a}	2.40^{a}
Number of leaves	5.41^{a}	3.92^{b}	4.11^{b}	4.37^{a}	4.33^{a}	4.74^{a}	4.04^{b}	5.18^{a}	4.22^{b}
Number of roots	18.93^{a}	6.93^{c}	9.52^{b}	11.52^{a}	12.70^{a}	11.15^{a}	12.00^{a}	10.96^{a}	12.41^{a}
BBT	33.72^{a}	11.56^{c}	17.56^{b}	20.55^{a}	21.59^{a}	20.21^{a}	21.95^{a}	20.16^{a}	20.23^{a}
BKT	12.40^{a}	4.05^{c}	7.32^{b}	8.04^{a}	8.03^{a}	7.68^{a}	8.10^{a}	7.88^{a}	7.78^{a}
Shoot:root ratio	3.30^{a}	2.23^{b}	3.92^{a}	3.08^{a}	3.24^{a}	3.12^{a}	3.09^{ab}	2.55^{b}	3.80^{a}
SQ	2.15^{a}	1.52^{b}	0.72^{c}	1.44^{a}	1.49^{a}	1.46^{a}	1.65^{a}	1.34^{b}	1.41^{b}
DQI	3.68^{a}	1.10^{b}	2.35^{ab}	2.46^{a}	1.97^{a}	2.71^{a}	2.20^{a}	3.02^{a}	1.92^{a}

Note: Numbers with the same letter indicate that the treatment is not significantly different at the 5% test level

Percentage of seedlings' life

The treatments affected different effects on each propagule growth. Although the effects differed, all treatment combinations showed a 100% plant survival percentage. External and internal factors influence the success of cuttings development. Internal factors are water availability, the content of food reserves (carbohydrates) in the cell tissue, and endogenous hormones in the cutting tissue. In comparison, external factors (environmental) include rooting media, humidity, temperature, light intensity, and cuttings preparation techniques. The growth of *R. apiculata* seedlings from complete propagule was better than that of seedlings from propagule cuttings, both upper and lower propagules, which may be because there are more food reserves in complete propagules and faster shoot and root growth compared to shoot and root growth in seedlings from propagule cuttings. In line with the statement of Hidayat (2016) that the growth of shoots and roots on propagule cuttings must go through several stages of growth and development until the formation of perfect roots and shoots. The process of shoot development can be divided into three stages, namely cell differentiation followed by the emergence of a group of meristem cells, differentiation of meristematic cell groups into shoot primordia, and growth with the emergence of new shoots, including the rupture of other hypocotyl tissues and the formation of vessels that connect the tissues on the cuttings (Kusmana et al. 2018). Young plants are more likely to show primary growth, such as the addition of height, roots, and the number of leaves. That makes it difficult to measure diameter growth in the seedling phase because it is one part of secondary growth that occurs in areas where primary growth has stopped.

Height growth of Rhizophora apiculata

The growth of *R. apiculata* seedlings was measured from the beginning of planting to the end of the observation (4 months), i.e., 16 weeks of observation (Figure 4). The increment of seedlings and new shoots growth are presented in Figures 5 and 6.

The combination of A0B1C1 treatment (complete propagules, mud and sand planting media, and giving PGR at a dose of 10,000 ppm) resulted in the most significant increase in height (27.8 cm) from the other treatment combinations with a difference of 0.2 cm from the control (A0B0C0), which was 27.2 cm. On the other hand, the

A1B0C2 treatment (top cutting of propagules, mud planting media, and giving of PGR dose of 15,000 ppm) gave the best incremental increase in the height of 15.3 cm compared to other combinations of cutting propagules. Meanwhile, for the increment of new shoot height, the combination of A0B2C2 treatment (complete propagules, planting media of mud+sand+compost, giving PGR dose of 15,000 ppm) resulted in the largest increment value (30.5 cm) with a difference of 2.7 cm from the control, which was 27.83 cm.

In the complete and upper propagule, shoots contain the hormone auxin, which can stimulate root growth. A balance in root and shoot growth can support better growth and development of seedlings. These shoots will later develop into perfect leaves. Leaves have a very important role, especially as a place for photosynthesis to take place. Photosynthate produced from photosynthesis is used to grow and form plant organs (Hidayat 2016).

Increase in diameter of Rhizophora apiculata

The increase in the diameter of *R. apiculata* seedlings was measured from the beginning of planting to the end of the observation (4 months), i.e., 16 weeks of observation (Figure 7). The diameter increment of seedlings and new shoots are presented in Figures 8 and 9. Based on Figure 8, the combination of treatment a0b1c0 (complete propagules, mud+sand planting media, without PGR) resulted in the highest diameter increment value of 2.97 mm with a difference of 1.59 mm with the control (a0b0c0), which was 1.38 mm. As for the cutting of propagules. a1b0c2 (top cuttings of propagules, growing media of mud, 15,000 ppm PGR) gave the best diameter increment value of 2.88 cm compared to other combinations of propagule cutting treatments. Meanwhile, for the incremental increase in diameter of new shoots, the combination of treatment a0b1c1 (whole propagules, planting media of mud+sand, giving PGR dose of 10,000 ppm) resulted in the largest increment value (4.23 cm) with a difference of 0.8 cm from the control, which was 3.43 cm.

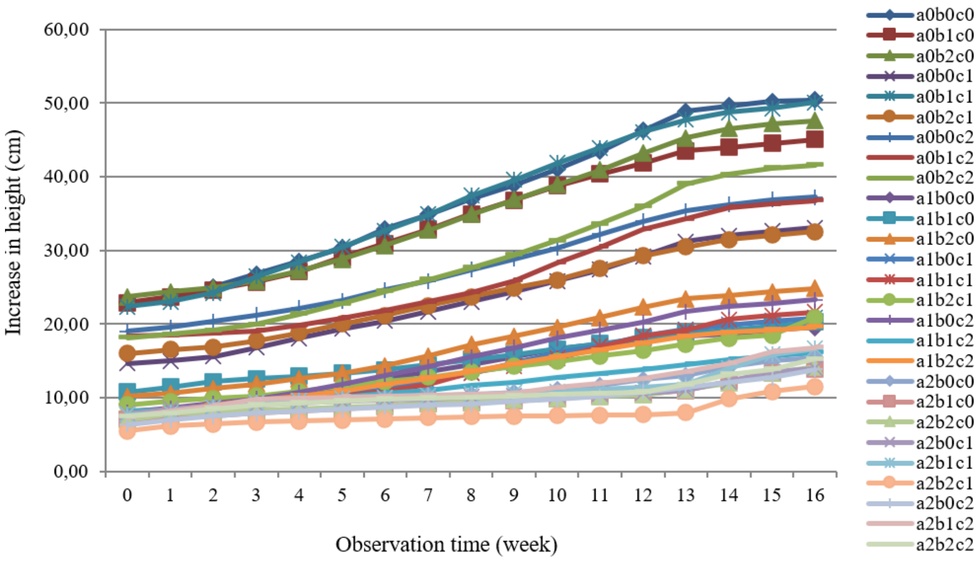


Figure 4. The increase in the height of *R. apiculata* in various treatment combinations

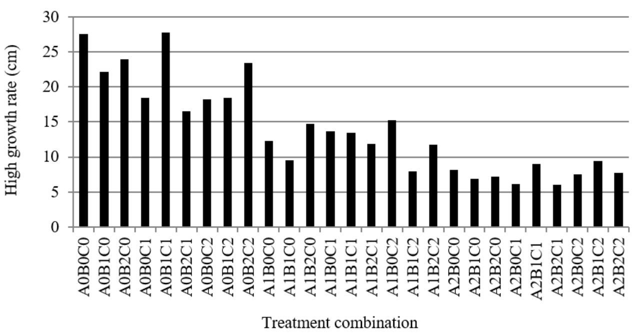


Figure 5. The incremental increment of *R. apiculata* in various treatment combinations

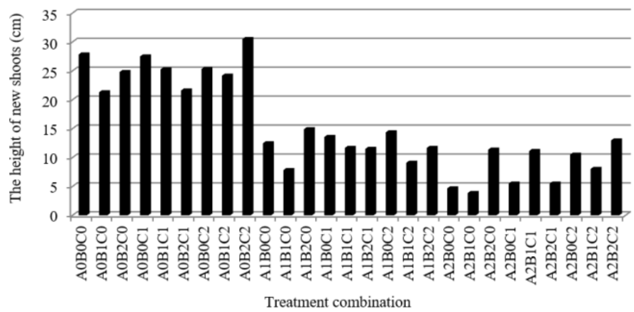


Figure 6. Increase in the height of new shoots of *R. apiculata* in various treatment combinations

That is in line with research conducted by Hidayat (2016), who carried out the cutting method on *Bruguiera gymnorrhiza* propagules: complete propagules produced the highest increment in diameter, and the lower propagule cuttings produced the lowest increment in diameter. The table shows that the increase in diameter was influenced by the interaction between the planting medium and the provision of PGR (BxC). The concentration requirements of growth regulators may vary for each type of plant to produce roots, even between varieties within a species. Likewise, giving the wrong concentration range can cause unexpected effects. In different concentrations, growth regulators can have the opposite effect, sometimes inhibiting plant growth because they cause toxicity to all plant tissues (Pidlisnyuk et al. 2022). In this case, it was assumed that there was an interaction of concentration and the right type of PGR, resulting in better diameter growth of the upper hypocotyl cuttings.

Number of leaves of Rhizophora apiculata

The increase in the number of leaves of *R. apiculata* seedlings from the beginning of planting to the end of observation (4 months) is 16 weeks of observation (Figure 10). It shows that the combination of treatments a2b0c1 (lower propagule, mud planting media, and 10,000 ppm PGR) and A2B1C1 (lower propagules, mud+sand planting media, and 10,000 ppm PGR) resulted in the largest increment of leaf number, namely seven leaves, with a difference of one leaf increment in the number of leaves with control (A0B0C0), which is six leaves. That was due to the growth of new shoots on the lower propagule cutting, which was more than one. Therefore, the number of leaves produced was more even though with a smaller size than the complete propagule and the upper propagule pieces, which only had one new shoot but with a larger leaf size. Root formation is a very important initial factor during plant growth in vegetative propagation through cuttings, especially on lower cuttings. In general, shoot formation and growth will occur after the roots are well formed due to injury, which results in the absence of buds for leaf growth, so it requires a relatively long time compared to upper cuttings (Hidayat 2016).

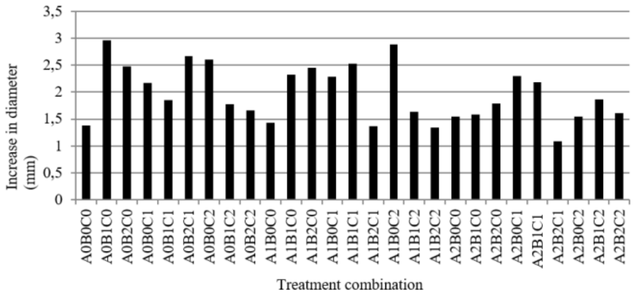


Figure 8. *R. apiculata* diameter growth increment in various treatment combinations

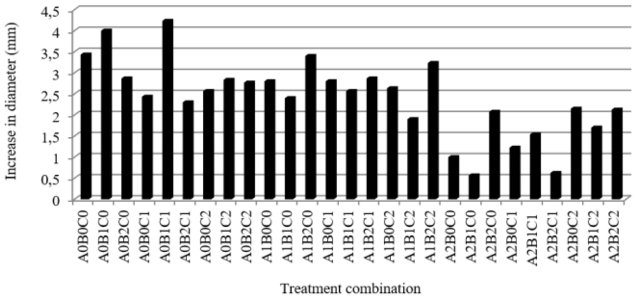


Figure 9. Increase in diameter of new shoots of *R. apiculata* in various treatment combinations

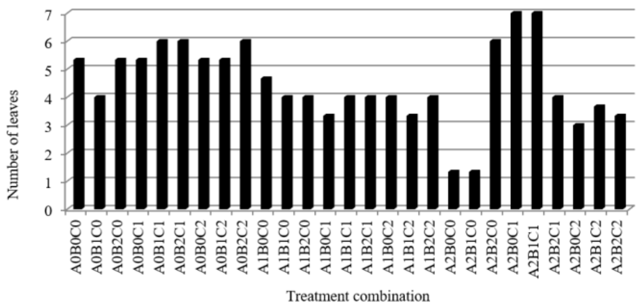


Figure 10. Increase in the number of leaves in various combinations of treatment on *R. apiculata*

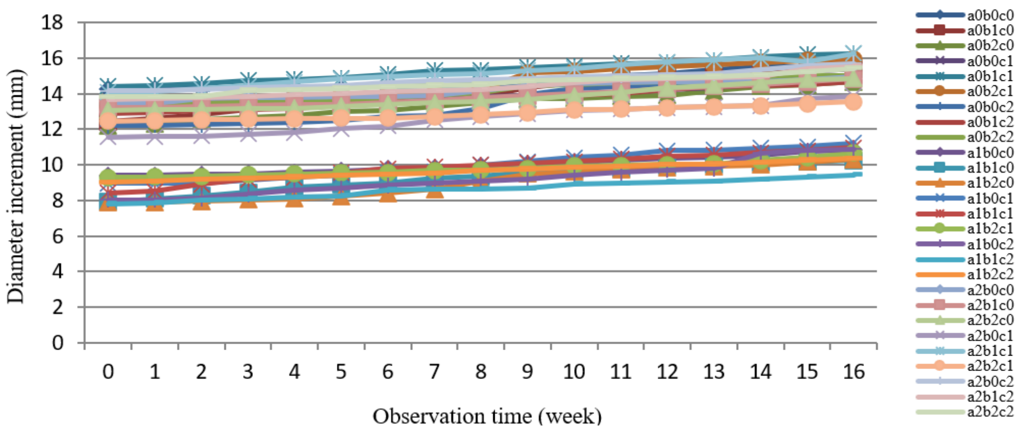


Figure 7. Growth of *R. apiculata* seedling diameter for 4 months in various combinations of hypocotyl cutting treatment (A), planting media (B) and giving PGR (C)

A B C

Figure 11. A. Whole propagule of 4 months old *R. apiculata*; B. upper section of 4 months old *R. apiculata*; C. 4 months old section of lower propagule of *R. apiculata*

Number of roots of Rhizophora apiculata

The roots of *R. apiculata* seedlings that grew consisted of 2 types: roots that grew on the propagule without cutting treatment (complete propagule) and propagule that was treated with cutting (upper and lower propagules). All treatment combinations showed root growth (Figure 13). The graph of the increase in the number of roots for 4 months is presented in Figure 12.

Figure 12 shows that the control (a0b0c0) produced the highest average number of roots, which was 22 roots. As for the cutting of propagules, a2b1c1 (lower propagules, growing media of mud+sand, giving PGR at a dose of 10,000 ppm) produced the highest average number of roots, which was 16.33 roots with a difference of 5.67 from the control. Based on this, it can be assumed that the presence of endogenous hormones and auxin in *R. apiculata* seedlings is sufficient. Therefore, exogenous hormones are unnecessary and can grow well under controlled conditions. According to Yusnita et al. (2018), hormones such as IBA and NAA were more effective than indole-3-acetic acid (IAA) in stimulating the root formation of plant cuttings. Although it did not affect root growth, root-promoting hormone treatment increased the T/R ratio. In addition, it is very influential on plant growth and development, especially leaf growth (Table 6).

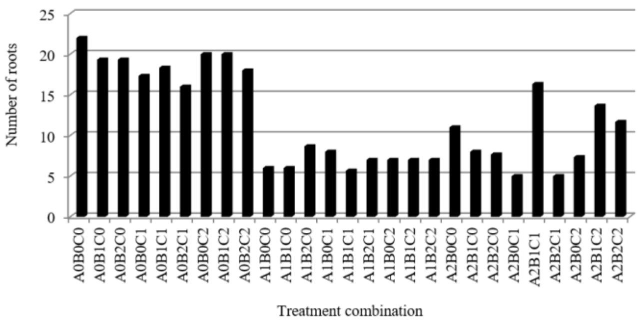
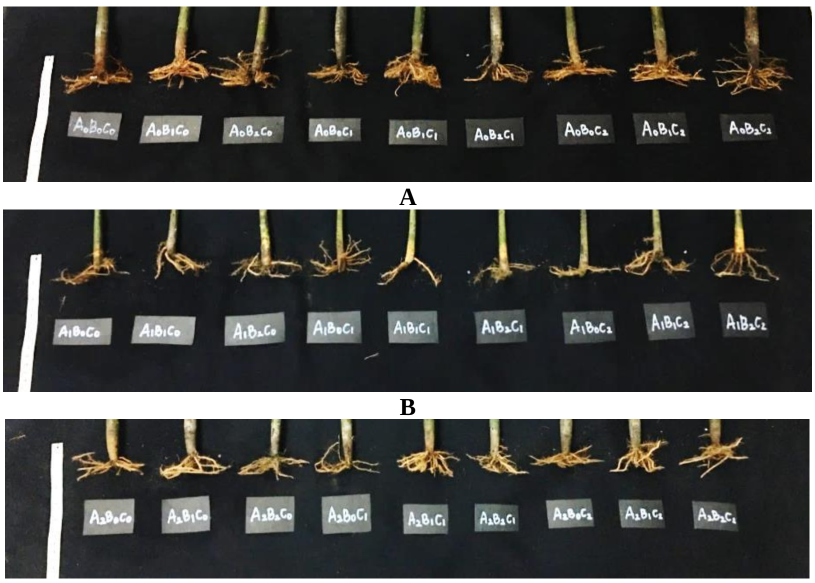


Figure 12. Root growth in each treatment combination of *R. apiculata*



A

B

C

Figure 13. A. Whole propagule root of 4 months old *R. apiculata*; B. 4 months old root of the upper propagule *R. apiculata*; C. 4 months old root of the lower propagule of *R. apiculata*

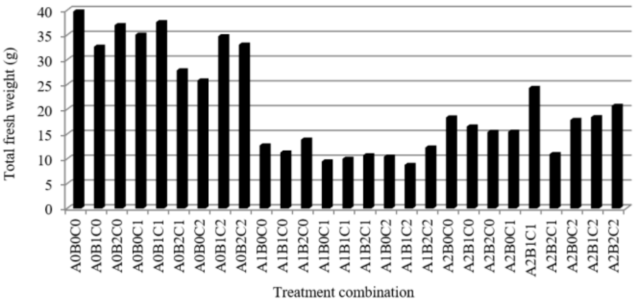


Figure 14. A. Total fresh weight of *R. apiculata* seedlings aged 4 months on various combinations of hypocotyl cutting treatment; B. Planting medium; C. PGR

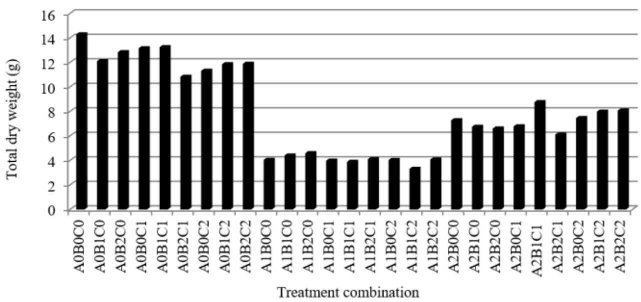


Figure 15. A. The total dry weight of *R. apiculata* seedlings aged 4 months in various combinations of hypocotyl cutting treatment; B. Planting medium; C. Giving PGR

Total fresh weight

Propagule cutting was the treatment that significantly affected the total fresh weight of *R. apiculata* seedlings, among other treatments (Table 6). The graph of the total fresh weight of *R. apiculata* seedlings aged 4 months in various treatment combinations is presented in Figure 14.

Figure 14 shows that a0 produces the largest total fresh weight, and a1 produces the smallest total fresh weight. The treatment combination that produces the largest total fresh weight, based on Figure 13, is found in control (a0b0c0), which is 39.74 grams. As for the cutting of propagules, the combination of treatment a2b1c1 (lower propagule, growing media of mud+sand, giving PGR at a dose of 10,000 ppm) gave the best total fresh weight value of 24.31 grams, with a difference of 15.43 grams with the control.

Total dry weight

Propagule cutting was the treatment that significantly affected the total dry weight of *R. apiculata* seedlings, among other treatments (Table 6). The graph of the total dry weight of *R. apiculata* seedlings aged 4 months in various treatment combinations is presented in Figure 15.

Figure 15 shows that A0 produces the largest total dry weight, and A1 produces the smallest total dry weight. The treatment combination that produces the largest total dry weight, based on Figure 15, is found in control (a0b0c0) 14.30 grams. As for the cutting of propagules, the combination of treatment a2b1c1 (bottom of propagule cutting, growing media of mud+sand, giving PGR dose of 10,000 ppm) gave the best total fresh weight value of 8.76 grams, with a difference of 5.54 grams with control.

The indicator that is commonly used to determine whether seedling growth is good or not is biomass. Biomass in this study consisted of total fresh weight and total dry weight. Total fresh weight is a parameter used to determine plant water requirements. The greater the total fresh weight of the seedling, the more water is absorbed. The total dry weight reflects the accumulation of organic compounds that plants have successfully synthesized from inorganic compounds (nutrients, water, and carbohydrates) (Ardhana et al. 2018). The total biomass value of complete propagules is used as a control and comparison for propagule cuttings to find a biomass value that is the same as or close to complete propagules; the use of this parameter is also found in research by Hidayat (2016) and Mulyani et al. (1999).

Based on Figures 14 and 15. the total fresh weight is directly proportional to the total dry weight of the seedlings. Seedlings from the complete propagule had the largest value, and the upper propagule had the smallest total fresh weight and total dry weight. The better or more efficient the physiological processes of the plant, the greater the dry weight of the plant. That means that plants can absorb available nutrients for use in the growth process (Hidayat 2016).

Shoot:root ratio

The results of the ANOVA test are presented in Table 6. shoot:root ratio was influenced by the cutting of propagules and the administration of PGR. The graph of shoot:root ratio of *R. apiculata* aged 4 months in various treatment combinations is presented in Figure 16.

Figure 16 shows that the lower cutting propagule (a2) produced the highest shoot:root ratio value compared to the complete and upper cutting propagules. The combination of treatments produces the largest shoot:root ratio, based on Figure 16, found in the combination of treatment a2b2c2 (lower propagule, planting media of mud+sand+compost, giving a PGR dose of 15,000 ppm) which is 7.18 grams with a difference of 4.04 grams with the control, namely 3.14 g. The shoot:root ratio value reflects the partition of photosynthate in plant growth. A shoot:root ratio value of more than 1 indicates more plant growth toward the shoots, while a shot:root ratio value of less than 1 indicates more plant growth toward the roots (Lang'at et al. 2012). Based on the study's results, it was shown that the shoot and root value in all treatment combinations is >1, which indicated that the availability of water and nutrients for plants was relatively optimal so that growth was more dominant to the shoots.

Sturdiness qoutient (SQ)

The results of the ANOVA test are presented in Table 7, SQ is affected by the cutting of propagules and the PGR. The SQ graph of *R. apiculata* aged 4 months in various treatment combinations is presented in Figure 17. This figure shows that complete propagules produced the highest SQ value compared to cutting propagules. The treatment combination A0B2C0 (complete propagules, planting medium mud+sand+compost, without PGR) produces the largest SQ value, which is 2.65, with a difference of 0.13 from the control, which is 2.52. According to Dushimimana et al. (2022), the value of good/optimum seedling sturdiness is not higher than 6. The smaller the SQ value, the more robust the plant and the higher the expected survival rate, especially in windy or dry places. A high sturdiness value indicates low survivability due to plant height and diameter imbalance.

Dickson Quality Index (DQI)

The results of the ANOVA test are presented in Table 6. the DQI value is only affected by the cut-propagule. The DQI graph of *R. apiculata* aged 4 months in various treatment combinations is presented in Figure 18.

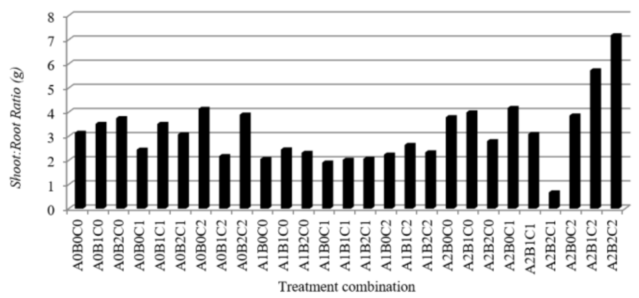


Figure 16. A. Value of shoot:root ratio of *R. apiculata* seedlings aged 4 months in various combinations of hypocotyl cutting treatment; B. Planting media; C. Giving PGR

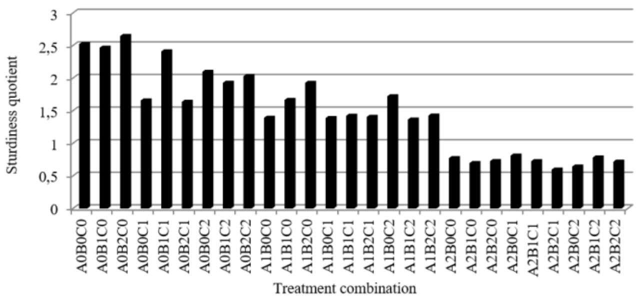


Figure 17. A. Sturdiness quotient (SQ) value of *R. apiculata* seedlings aged 4 months in various combinations of hypocotyl cutting treatment; B. Planting media; C. Giving PGR

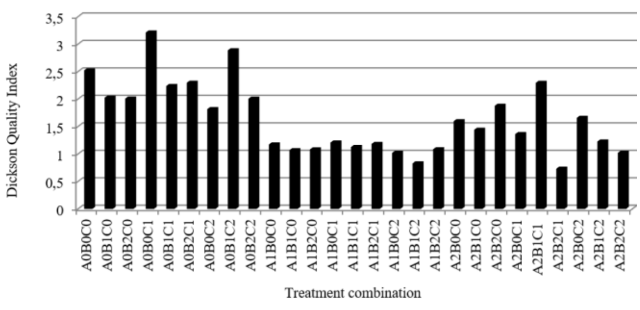


Figure 18. A. Dickson quality index value of 4-month-old R. apiculata seedlings in various combinations of hypocotyl cutting treatment; B. Planting medium; C. Giving PGR

Propagule cut has a significant effect on the DQI value. Figure 18 shows that a0 produces the largest DQI value and a1 produces the smallest value. The combination of a0b0c1 treatment (complete propagules, mud planting media, giving PGR dose of 10,000 ppm) resulted in the highest DQI value of 3.21 with a difference of 0.69 with the control, which was 2.52. Based on the statement of Nyoka et al. (2018) that the seed quality index value for seedlings should be more than 0.2. Seedlings whose value is less than 0.2 are difficult to grow in the field. Therefore, the higher the value of the seed quality index, it will guarantee the quality and ability of the seeds to grow well in the field.

Furthermore, all treatment combinations showed a 100% survival percentage with complete plant parts (leaves, stems, and roots). The best treatment combination was complete propagules with mud+sand seedling media and 10,000 ppm PGR (a0b1c1). However, the cut-propagule still showed good growth with a combination of bottom-cutting propagules, mud+sand, PGR 10,000 ppm (a2b1c1) that showed the best performance so that it can be used as an alternative to mass vegetative reproduction in mangrove rehabilitation activity.

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