

The growth performance of *Kandelia candel* hypocotyl cuttings seedlings for mangrove rehabilitation in Indonesia

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Abstract. Nugraha LA, Kusmana C, Hartoyo APP. 2024. The growth performance of *Kandelia candel* hypocotyl cuttings seedlings for mangrove rehabilitation in Indonesia. *Biodiversitas* 25: 2683-2695. *Kandelia candel* (L.) Druce is one of the mangrove species threatened with extinction and continues to decline in number yearly in Indonesia. Effective and efficient propagation techniques are urgently needed to reduce the risk of extinction and accelerate the rehabilitation of this mangrove species. This study aimed to analyze the growth performance of *K. candel* hypocotyl cuttings and determine the best combination treatments. The type of this study was experimentally carried out in a greenhouse. The experimental design was a completely randomized three-factor factorial design with three factors and three replications for each factor: hypocotyl cuttings, planting media, and growth regulators. Based on the variance test resulted in the interaction between the hypocotyl cutting, planting media, and plant growth regulator had a significant effect on seedling height, number of leaves, total weight biomass, sturdiness quotient, and Dickson Quality Index at the 5% test level. The experiment was a success, with all combinations of treatments showing a survival rate of 100%. The best growth of hypocotyl cuttings was found by combining the bottom part of hypocotyl, mud + sand planting media, and a plant growth regulator of 15,000 ppm. The hypocotyl-cutting method can be an alternative method to provide quality seedlings for mangrove rehabilitation activities.

Keywords: Hypocotyl cuttings, mangrove, rehabilitation, vegetative propagation

INTRODUCTION

Mangrove forests are multifunctional forest ecosystems (ecological, chemical, economic, and social) and have an essential role in coastal areas (Das et al. 2022). Physically, mangroves can stabilize land, prevent abrasion or intrusion, reduce coastal and river bank erosion, maintain biodiversity (Srikanth et al. 2016), can protect land (coasts) from storms (Méndez-Alonzo et al. 2015), wind tornadoes, high sea waves, and hazards such as tsunamis (Zhang et al. 2015). Chemically, mangroves can neutralize and precipitate pollutants so that the toxic levels in pollutants decrease (Wilda et al. 2020). Also, mangroves can store carbon and absorb carbon dioxide (Isnani and Masjud 2024). Ecologically, mangroves can be a breeding and foraging place for fauna around the mangroves. Economically, mangroves can produce forest products in the form of wood (firewood, charcoal, broom, roof, paper, building materials) and non-wood (flour, syrup, dodol, crackers, tea, sugar, chocolate, medicine) as a source of livelihood and potentially be an ecotourism site (Rugayah et al. 2017). However, the distribution of mangroves in the world is limited, only in 124 tropical and subtropical countries with an area of 15.2 million ha (Lavieren et al. 2015).

The most abundant mangroves are in Indonesia, which has an area of 3,364,076 ha or around 29% of the world's mangrove area (MoEF 2021). In line with the area of mangroves, mangrove forest destruction in Indonesia is also the largest in the world (Hamilton and Casey 2016)

over the last decade, namely 182,091 ha (Arifanti et al. 2021). Mangrove damage in Indonesia occurs due to uncontrolled exploitation and conversion of mangrove forests, which are intended for oil palm plantations, fish ponds, charcoal making, infrastructure development, and entertainment venues, which have an impact on environmental aspects, oil pollution, heavy metals, natural disasters, etc. Damaged mangroves have an impact on decreasing biodiversity, loss of land cover, and reduced populations of flora, fauna, and microorganisms, thus increasing the chances of species extinction (Löf et al. 2019).

As a country with the widest mangroves in the world, Indonesia is also rich in mangrove biodiversity. Over 40 of 50 "True mangrove" species worldwide are found in Indonesia and can form pure stands (Tomlinson 2016). However, there is one type of mangrove that has the potential to become extinct in Indonesia, namely *Kandelia candel* (L.) Druce or what Indonesians know as *Pisang-Pisang*. This species belongs to the Rhizophoraceae family, which has various benefits. The stem and twigs are firewood and stakes (Rugayah et al. 2017). All of the parts have anti-diabetic properties (Patra et al. 2020). The bark, flowers, and leaves can be antiviral and antimicrobial. Moreover, the leaves contain alpha-amylase, which can be anti-diabetic in preventing diabetes mellitus (Shettar and Vedamurthy 2017). However, this species has the potential to become extinct because it is only found in West Kalimantan and South Sumatra (Marisa et al. 2020) with small growing areas and small populations, namely along

the intertidal zone, especially with brackish water conditions such as river banks, deltas, and estuaries (Malabrigo and Pasion 2022). Apart from that, according to Zhang et al. (2019), the cultivation of *K. candel* is still limited.

Rehabilitation efforts through planting are urgently needed to reduce the risk of *K. candel* extinction (Nugraha et al. 2022). However, the propagules with high-quality criteria, free from pest/disease, and ready for planting are still limited due to the lack of propagules number, and it will decrease when the propagules are collected outside the ripe season, especially *K. candel*. According to Marisa et al. (2020), this species has a ripe season from November to January.

The vegetative propagation method using hypocotyl cuttings can be an alternative in procuring *K. candel* seedlings because the number of propagules used is more efficient and economical by cutting the hypocotyl into two parts. Previous research on hypocotyl cuttings has been successfully carried out on *Bruguiera gymnorrhiza* (L.) Lam., where the bottom hypocotyl cuttings grow better than the upper hypocotyl cuttings (Kusmana et al. 2018). The appropriate treatment combination needs to be investigated to achieve optimum growth. This study aimed to analyze the growth performance of the seedlings of *K. candel* using hypocotyl cuttings and determine the right combination of treatments to get the best growth rate for *K. candel* seedlings using hypocotyl cuttings.

MATERIALS AND METHODS

Study area

This study was conducted in the greenhouse of the Ecology Division, Department of Silviculture, Faculty of Forestry and Environment, Institut Pertanian Bogor, Bogor, Indonesia for 4 months from May to August 2022 (Figure 1). The *K. candel* propagule collection was carried out in April 2022 within the Payung Island region, South Sumatra, Indonesia. The coordinates are 02°22'30.6'' S 104°54'51.5'' E (Figure 1). Mud media was carried out in the Elang Laut mangrove area, Pantai Indah Kapuk, North Jakarta.

Tools and materials

The tools utilized in this study were anti-heat plastic, autoclaves, calculators, cameras, cotton wool thread, cutters, digital calipers, digital scales, markers, ovens, rulers, scopes, stationery, styrofoam boxes, styrofoam cups. The materials used were compost, *K. candel* hypocotyl, mud, Plant Growth Regulators (PGR), polybags (15 cm × 20 cm), sand, and water.

Procedures

Kandelia candel propagules preparation

The number of *K. candel* propagules used in this study was 81 propagules. Several factors must be considered when picking propagules: seed source, season, quality, and maturity. The seed source (mother tree) must be healthy and free from disturbances and diseases, and picking out of season can still be done if the need for propagules is less. The qualified propagule characteristics are healthy and mature, free from pests/diseases. Mature propagules were characterized as a brownish-yellow ring between the cotyledons and the hypocotyl (minimum length of 30 cm).

Propagules were picked starting from the pericarp (a hood-like structure above the cotyledons that cover the plumula) so they were durable and did not sprout quickly. After the propagules were collected, they were re-selected according to their quality and maturity. Then, the propagules were washed first with fresh water to maintain the freshness of the propagules and begin adaptation to the new environment before entering the storage stage (Figure 2.A).

Propagule storage in coconut fiber media, which has relatively wet containers, was better. The propagule storage container uses a styrofoam box with a capacity of 15 kg, which has previously been perforated to ensure air circulation. Next, the propagules are placed in stages into a styrofoam box, each layer covered with coconut fiber and wrapped in a burlap sack as the final layer. The purpose of using coconut fiber and jute sacks is to maintain humidity between rooms in relatively wet styrofoam. Finally, the propagules were stored in good condition and safely sent to the nursery. Propagules persistence for 14 days (Figure 2.B).

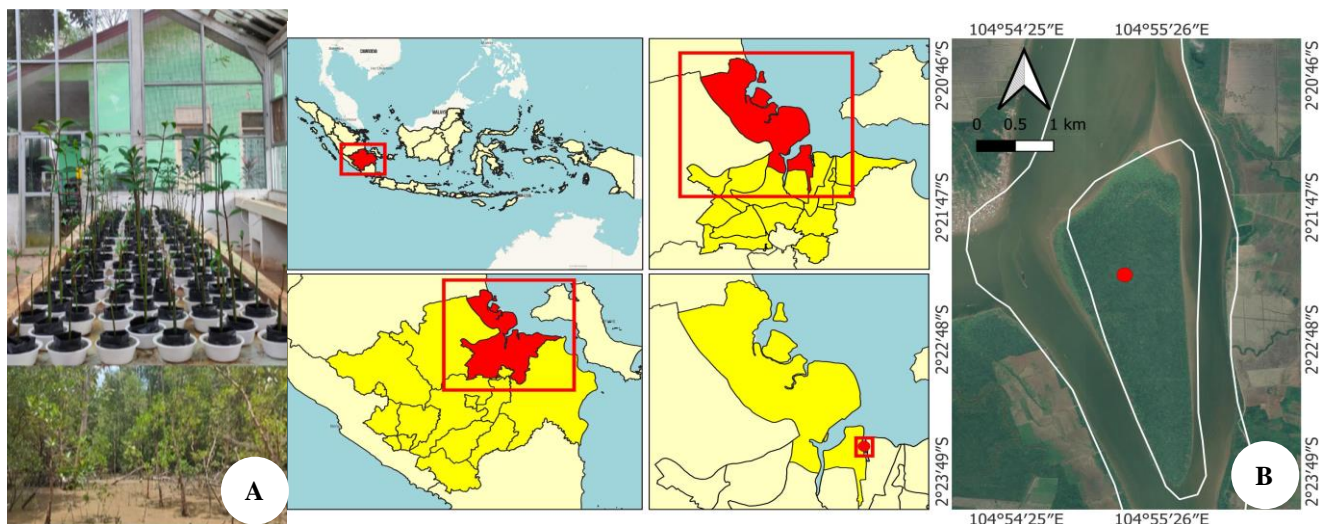


Figure 1. A. Nursery location; and B. *Kandelia candel* propagules collection location



Figure 2. A. Characteristics of mature *Kandelia candel* propagules; B. The *K. candel* propagules after 14 days; C. Treatment of *K. candel* hypocotyl cuttings

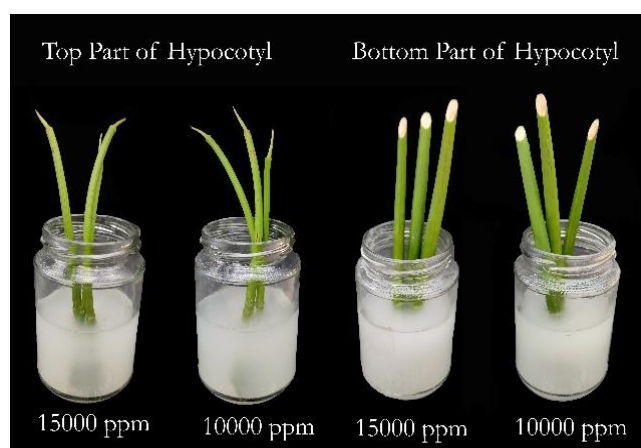


Figure 3. Soaking *Kandelia candel* hypocotyl cuttings using PGR

Planting media preparation

The planting media used was mud, sand, and compost. The sand used was sieved first so that the sand obtained was fine. The preparation of planting media consists of collecting media and sterilizing the media. The sterilization medium was wrapped in anti-heat plastic using an autoclave at 121°C for 15 minutes and then incubated in an open space for one day. The treatment of planting media consisted of mud, mud+sand, and mud+sand+compost (one-to-one ratio for each element in the treatment) with a weight of 500 gr/polybag.

Hypocotyl cutting

There were three hypocotyl treatments: intact hypocotyl, the top part of hypocotyl, and the bottom part of hypocotyl. The cut was made obliquely at an angle of 45° into two equal parts (Figure 2.C). The purpose of oblique cuts was to widen the cut surface for optimal shoot growth and avoid the potential for fungus. Mushrooms can grow if there is standing water due to the hypocotyl being cut flat.

Immersion of hypocotyls using PGR

The hypocotyl was immersed in PGR solutions of 0 ppm, 10,000 ppm, and 15,000 ppm (Kusmana et al. 2018) for 15 minutes each (Figure 3). After soaking, the hypocotyl was aerated before planting to allow the PGR to adhere to it and not easily wash away when watered. This soaking method using PGR promotes root growth at the base of the cut hypocotyl.

Planting and maintenance

Planting occurred at 15.00-17.00 Western Indonesian Time when the polybags' planting media and holes were made. The required depth of the planting hole was one-third of the hypocotyl, and the holes were closed again after planting. Maintenance was conducted by controlling the water stagnation in each styrofoam cup. Controlling the volume of water was carried out daily with stagnant conditions filling the neck of the styrofoam cup. Controlling waterlogging maintains water availability in the seedlings and optimizes their growth. The water used was fresh.

Observation and measurement

The variables observed in this study were seedling height, seedling stem diameter, number of leaves, number of new shoots, the height of new shoots, diameter of new shoots, wet weight of biomass, and dry weight of biomass. The observation period for the parameters of seedling height, stem diameter of seedlings, number of leaves, number of new shoots, the height of new shoots, and diameter of new shoots was measured once a week for four months. At the same time, the observation period for the parameters of the number of roots, wet weight of biomass, and dry weight of biomass was observed at the end of the study.

Experimental design and treatment

The growth performance of *K. candel* seedlings was analyzed using a completely randomized design of factorial three factors with three replications. Those treatments were: hypocotyl cutting (h0: intact hypocotyl, h1: the top part of hypocotyl, h2: the bottom part of hypocotyl),

planting media (m0: planting media of mud, m1: planting media of mud + sand, m2: planting media of mud + sand + compost), PGR (g0: 0 ppm, g1: 10,000 ppm, g2: 15,000 ppm).

Data analysis

Data analysis is based on the following observation variables:

Survival Rate (SR) was obtained using the following formula (Thompson 1985):

$$SR = \frac{T_t}{T_0} \times 100\%$$

Where:

T_t : Number of live plants at the time of observation

T_0 : Number of plants when planted

The current weekly increment was obtained using the following formula (Prodan 1968):

$$\Delta x = \frac{x_n - x_{n-1}}{t_n - t_{n-1}}$$

Where:

Δx : Current weekly increment of seedling height (cm); seedling stem diameter (mm); leave number

x_{n-1} : Value before week n

t_{n-1} : Measurement week before week n

x_n : Value week n

t_n : Measurement week

Shoot-Root Ratio (SRR) was obtained using the following formula (Racey et al. 1983):

$$SRR = \frac{\text{Root dry mass (g)}}{\text{Shoot dry mass (g)}}$$

The Sturdiness Quotient (SQ) was obtained using the following formula (Thompson 1985):

$$SQ = \frac{\text{Seedling height (cm)}}{\text{Seedling diameter (mm)}}$$

The seedling quality index is calculated based on the Dickson Quality Index (DQI) formula with the following equation (Dickson et al. 1960):

$$DQI = \frac{\text{Total dry weight (root + stem)}}{SQ + SRR}$$

Weighting aims to determine the best combination. Weighting is divided into 10 classes (K) with an interval of 1 - 10 (smallest - largest). The class width (C) is based on the following formula:

$$C = \frac{\text{The greatest value of a treatment}}{\text{number of class}}$$

The research data obtained continued with the ANOVA and DMRT's test to determine whether there is a significant effect of the difference in treatment of the variables observed at the 5% test level using Statistical Analysis Software version 9.1.3.

RESULTS AND DISCUSSION

The *K. candel* stand grows sporadically on riverbanks and the banks on Payung Island, Indonesia. Most are found in the sapling and pile phases with a height of up to 5-7 meters. The bark is greyish and has a mixture of a reddish-brown color with a smooth surface and lenticels. The leaves are elliptical-round elongated, and the tips of the leaves are rounded to slightly pointed, with the edges of the leaves shrinking inward. The position of the leaves crossed. The flowers are white. Propagules are green with a blend of green and yellow at the ends. Propagule types is vivipary. Characteristics of *K. candel* are presented in Figure 4.

Research status of mangrove rehabilitation using *Kandelia candel*

The *K. candel* is a type of mangrove rarely used in mangrove forest rehabilitation in Indonesia and the world (Table 1). In the last ten years, there has been a scientific article in Indonesia out of 4 scientific articles related to the cultivation of *K. candel* in the world. Its propagation uses generative propagation methods.

Soil and water analysis

The soil analysis of the planting media showed that the soil pH at all planting media is slightly alkaline and close to neutral (Table 2). The water analysis of *K. candel* seedling showed that the *K. candel* seedling could grow with fresh water in the greenhouse (Table 3).

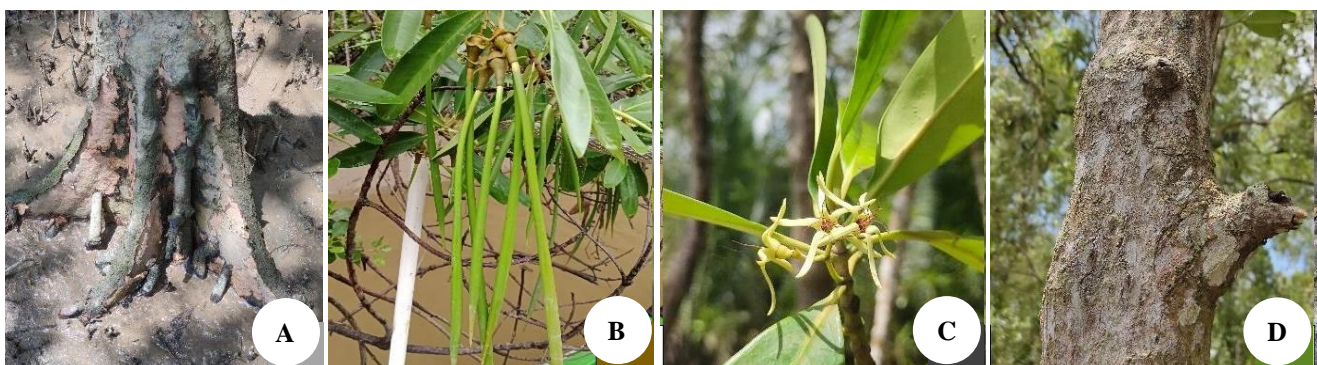


Figure 4. Characteristics of *Kandelia candel*: A. Root; B. Stem; C. Flower; D. Leaf and propagule

Table 1. Mangrove rehabilitation using *Kandelia candel* in the world (2014-2024)

Rehabilitation location	Source	Propagation methods
Sembilang National Park, Indonesia	Sarno et al. (2020)	Generative
Yanpu Bay, Zhejiang, China	Zhang et al. (2019)	Generative
Yanpu Bay, Zhejiang, China	Lai et al. (2021)	Generative
Gimaloto, Sorsogon, Philippines	Malabrigo and Pasion (2022)	Generative

Table 2. Soil analysis test planting media of *Kandelia candel* seedling

Test parameters		Test sample		
		m0	m1	m2
pH	H ₂ O	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 ₂ O 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 ₂ O	Available (mg/Kg)	0.9	1.2	1.2
	Potential (mg/100g)	227 (very high)	150 (very high)	232 (very high)
Exchangeable cation	K ⁺ (cmol(+)/kg)	1.93 (very high)	0.85 (high)	2.14 (very high)
	Na ⁺ (cmol(+)/kg)	2.21 (very high)	0.76 (medium)	1.09 (very high)
	Ca ²⁺ (cmol(+)/kg)	34.80 (very high)	10.86 (medium)	21.67 (very high)
	Mg ²⁺ (cmol(+)/kg)	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⁺ (cmol(+)/kg)	< 0.05	< 0.05	< 0.05
	H ⁺ (cmol(+)/kg)	0.25	0.17	0.19
Salinity (‰)		0,60 (very low)	0.24 (very low)	0.40 (very low)
Texture 3 fractions (%)	Klei	17	73	75
	Dust	27	11	20
	Sand	56	16	5
Texture class		clay	Loamy sand	Loamy sand

Note: m0: mud; m1: mud + sand; m2: mud + sand + compost. Test by PT Biodiversitas Biotechnology Indonesia, Indonesian Center for Biodiversity and Biotechnology (ICBB)

Table 3. Water condition of *Kandelia candel* seedling in The Greenhouse and Payung Island (Habitat), South Sumatra, Indonesia

Place	Test parameter		
	Water temperature (°C)	Water salinity (‰)	Water pH
Payung Island (habitat)	29-30	4-9	6.5
Greenhouse	30	0	6.5

The growth performance of *K. candel* seedlings

The percent survival of *K. candel* seedlings is 100%. This shows that the planting has been successfully propagated with or without hypocotyl cuttings. The ANOVA test showed the interaction between the hypocotyl cuttings of the planting media and PGR had a significant effect on five parameters of *K. candel* seedling growth, namely seedling height, number of leaves, total wet weight, Sturdiness quotient, and Dickson Quality Index at a 5% test level (Table 4).

Seedling height, the DMRT test (Table 5) showed that the h0m1g0 (intact hypocotyl, mud + sand planting media, and PGR 0 ppm) significantly differed and produced the highest increment, reaching 51.3 cm (Figure 5). On the hypocotyl cuttings, the h2m1g2 (the bottom part of hypocotyl, mud + sand planting media, and PGR 15,000 ppm) significantly differed and produced the highest

increment of seedling height on hypocotyl cuttings, reaching 30 cm (Figure 5). Number of leaves, the DMRT test (Table 6) showed that the h0m2g0 (intact hypocotyl, mud + sand + compost planting media, and PGR 0 ppm) and the h0m0g1 (intact hypocotyl, mud planting media, and PGR 10,000 ppm) significantly differed and were the best combination, reaching ten pieces (Figure 5). On hypocotyl cuttings, the best combination was the h2m1g0 treatment combination (the bottom part of hypocotyl, mud + sand planting media, and PGR 0 ppm), i.e., eight (Figure 5).

Total wet weight, the DMRT test (Table 7) showed that the h0m1g2 (intact hypocotyl, mud + sand planting media, and PGR 15,000 ppm) significantly differed and was the best combination, reaching 31.8 g (Figure 5). On hypocotyl cuttings, the h2m0g0 (the bottom part of hypocotyl, mud planting media, and PGR 0 ppm) significantly differed and was the best combination, reaching 14 g (Figure 5).

Sturdiness quotient, the DMRT test (Table 8) showed that the h0m1g0 (intact hypocotyl, mud + sand planting media, and PGR 0 ppm) significantly differed and was the best combination, i.e., 4.3 (Figure 5). On hypocotyl cuttings, the h1m0g0 (the top part of hypocotyl, mud planting media, and PGR 0 ppm) significantly differed and was the best combination, i.e., 2 (Figure 5). DQI, the DMRT test (Table 9) showed that the h0m1g2 (intact hypocotyl, mud + sand planting media, and PGR 15,000 ppm) significantly differed and was the best combination, i.e., 1.6 (Figure 5). On hypocotyl cuttings, the h2m1g2 (the bottom part of hypocotyl, mud + sand planting media, and PGR 15,000 ppm) significantly differed and was the best combination, i.e., 1.1 (Figure 5).

The combination of two factors significantly affected the shoot height, shoot diameter, and shoot-root ratio at a 5% test level (Table 3). Shoot height, the DMRT test (Table 10-12) showed that the h0m0 (intact hypocotyl and mud planting media), the h0g0 (intact hypocotyl and 0 ppm PGR), and the m0g0 (mud planting media and 0 ppm PGR) were significantly affected. The highest increment was the h0m0g1 (intact hypocotyl, mud planting media, and 10,000 ppm PGR), reaching 42.3 cm (Figure 5). The hypocotyl cuttings significantly affected the h2m1 (the bottom hypocotyl and mud + sand planting media) and h2g0 (the bottom hypocotyl and 0 ppm PGR). The highest increment was h2m1g0 (the bottom part of hypocotyl, mud + sand planting media, and 0 ppm PGR), reaching 28 cm (Figure 5).

Shoot diameter, the DMRT test (Tables 10-12) showed that the h0m0 (intact hypocotyl and mud planting media), the h0g0 (intact hypocotyl and 0 ppm PGR), and the m0g0 (mud planting media and 0 ppm PGR) were significantly affected. The highest increment was the h0m0g0 (intact hypocotyl, mud planting media, and 0 ppm PGR), reaching 5.6 mm (Figure 5). The hypocotyl cuttings significantly affected the h2m1 (the bottom hypocotyl and mud + sand planting media) and the h2g0 (bottom hypocotyl and 0 ppm PGR). The highest increment was the h2m1g1 (the bottom part of hypocotyl, mud + sand planting media, and 10,000 ppm PGR), reaching 4.5 mm (Figure 5).

Shoot-root ratio, the DMRT test (Tables 11-12) showed that the h0g2 (intact hypocotyl and 15,000 ppm PGR) and the m0g1 (mud planting media and 10,000 ppm PGR) were significantly affected. The best combination was the

h0m1g1 (intact hypocotyl, mud + sand planting media, and PGR 10,000 ppm), i.e., 5 (Figure 5). The m2g0 (mud + sand + compost planting media) and the h2g0 (bottom hypocotyl and PGR 0 ppm) were significantly affected by hypocotyl cuttings. The best combination was the h2m2g0 treatment combination (the bottom part of hypocotyl, mud + sand + compost planting media, and PGR 0 ppm), i.e., 4.7 (Figure 5).

The combination of one factor significantly affected four parameters: seedling diameter, root number, shoot number, and total dry weight at a 5% test level (Table 13). Seedling diameter, the DMRT test (Tables 13-14) showed that the h0 (intact hypocotyl) and the m0 (mud planting media) were significantly affected. The highest increment was the h0m2g0 (intact hypocotyl, mud + sand + compost planting media, and PGR 0 ppm), reaching 16 mm (Figure 5). The h2 (the bottom part of hypocotyl) and the m1 (mud + sand planting media) were significantly affected by hypocotyl cuttings. The highest increment was h2m2g0 (the bottom part of hypocotyl, mud + sand planting media, and PGR 0 ppm), reaching 15 mm (Figure 5).

Root number, the DMRT test (Table 13) showed that the h0 (intact hypocotyl) was significantly affected. The best combination was the h0m1g2 (intact hypocotyl, mud + sand planting media, and PGR 15,000 ppm), i.e., 386 roots (Figure 5). On hypocotyl cuttings, the h2 (the bottom part of hypocotyl) was significantly affected. The best combination was the h2m1g2 (the bottom part of hypocotyl, mud + sand planting media, and PGR 15,000 ppm), i.e., 210 roots (Figure 5). Shoot number: The DMRT test (Table 13) showed that the h2 (the bottom part of the hypocotyl) was significantly affected. The best combination was the h2m1g0 treatment combination (bottom part of hypocotyl, mud + sand planting media, and PGR 0 ppm), i.e., 1.6 shoots (Figure 5).

Total dry weight, the DMRT test (Table 13) showed that the h0 (intact hypocotyl) was significantly affected. The best combination was the h0m1g2 (intact hypocotyl, mud + sand planting media, and PGR 15,000 ppm), reaching 10.2 g (Figure 5). On hypocotyl cuttings, the h2 (the bottom part of hypocotyl) was significantly affected. The best combination was the h2m0g0 (the bottom part of hypocotyl, mud planting media, and PGR 0 ppm), which reached a weight of 4.4 g (Figure 5).

Table 4. The ANOVA test of each parameter on the growth of *Kandelia candel* seedlings

Parameter	Hypocotyl cutting (H)	Planting media (M)	Plant growth regulator (G)	H × M	H × G	M × G	H × M × G
Seedling height	*	*	*	*	*	ns	*
Seedling diameter	*	*	ns	ns	ns	ns	ns
Shoots height	*	*	*	*	*	*	ns
Shoots diameter	*	*	ns	*	*	*	ns
Shoots number	*	ns	ns	ns	ns	ns	ns
Root number	*	ns	ns	ns	ns	ns	ns
Leaves number	*	ns	ns	ns	ns	ns	*
Total wet weight	*	*	*	*	*	ns	*
Total dry weight	*	ns	ns	ns	ns	ns	ns
Shoot-root ratio	*	ns	ns	ns	*	*	ns
Sturdiness quotient	*	*	*	ns	ns	ns	*
Dickson Quality Index	*	*	*	*	ns	ns	*

Note: *: significant at a 5% test level; ns: not significant at a 5% test level

Table 5. The DMRT test of interaction among hypocotyl cuttings, planting media, and PGR on the seedling height of *Kandelia candel* seedlings

Hypocotyl cutting (H)	Planting media (M)	Plant growth regulator (G)		
		0 ppm (g0)	10.000 ppm (g1)	15.000 ppm (g2)
Intact hypocotyl (h0)	Mud (m0)	53.40 ^{ab}	52.47 ^{ab}	45.53 ^b
	Mud + sand (m1)	55.00 ^a	50.77 ^{ab}	50.33 ^{ab}
	Mud + sand + compost (m2)	50.77 ^{ab}	46.70 ^{ab}	45.13 ^b
The top part of hypocotyl (h1)	Mud (m0)	24.60 ^{def}	15.60 ^{gh}	30.27 ^{cd}
	Mud + sand (m1)	14.13 ^{gh}	24.43 ^{def}	29.40 ^{cde}
	Mud + sand + compost (m2)	18.37 ^{fg}	7.43 ^h	18.00 ^{fg}
The bottom part of hypocotyl (h2)	Mud (m0)	30.27 ^{cd}	21.37 ^{efg}	24.80 ^{def}
	Mud + sand (m1)	31.03 ^{cd}	27.57 ^{cde}	34.9 ^c
	Mud + sand + compost (m2)	15.53 ^{gh}	20.77 ^{efg}	18.20 ^{fg}

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

Table 6. The DMRT test of interaction among hypocotyl cuttings, planting media, and PGR on the leaves number of *Kandelia candel* seedlings

Hypocotyl cutting (H)	Planting media (M)	Plant growth regulator (G)		
		0 ppm (g0)	10.000 ppm (g1)	15.000 ppm (g2)
Intact hypocotyl (h0)	Mud (m0)	9.33 ^{ab}	10.00 ^a	8.67 ^{abc}
	Mud + sand (m1)	9.33 ^{ab}	8.00 ^{abcd}	8.00 ^{abcd}
	Mud + sand + compost (m2)	10.00 ^a	9.33 ^{ab}	8.00 ^{abcd}
The top part of hypocotyl (h1)	Mud (m0)	5.33 ^{cdef}	4.00 ^{ef}	6.00 ^{bcdef}
	Mud + sand (m1)	4.00 ^{ef}	6.00 ^{bcdef}	6.00 ^{bcdef}
	Mud + sand + compost (m2)	6.00 ^{bcdef}	2.67 ^f	4.67 ^{def}
The bottom part of hypocotyl (h2)	Mud (m0)	8.33 ^{abcde}	6.67 ^{abcde}	4.67 ^{def}
	Mud + sand (m1)	9.33 ^{ab}	6.00 ^{bcdef}	6.67 ^{abcde}
	Mud + sand + compost (m2)	5.67 ^{cdef}	7.33 ^{abcde}	7.33 ^{abcde}

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

Table 7. The DMRT test of interaction among hypocotyl cuttings, planting media, and PGR on the total wet weight of *Kandelia candel* seedlings

Hypocotyl cutting (H)	Planting media (M)	Plant growth regulator (G)		
		0 ppm (g0)	10.000 ppm (g1)	15.000 ppm (g2)
Intact hypocotyl (h0)	Mud (m0)	23.65 ^{de}	26.04 ^{cd}	30.23 ^{ab}
	Mud + sand (m1)	28.19 ^{bc}	25.29 ^{cd}	31.84 ^a
	Mud + sand + compost (m2)	20.49 ^e	22.07 ^e	21.21 ^e
The top part of hypocotyl (h1)	Mud (m0)	4.86 ⁱ	5.99 ⁱ	6.81 ⁱ
	Mud + sand (m1)	3.52 ⁱ	5.83 ⁱ	6.48 ⁱ
	Mud + sand + compost (m2)	3.76 ⁱ	4.46 ⁱ	5.01 ⁱ
The bottom part of hypocotyl (h2)	Mud (m0)	14.28 ^f	10.05 ^h	12.99 ^{fgh}
	Mud + sand (m1)	13.10 ^{fgh}	12.33 ^{fgh}	12.17 ^{fgh}
	Mud + sand + compost (m2)	13.59 ^{fg}	10.88 ^{gh}	12.71 ^{fgh}

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

Table 8. The DMRT test of interaction among hypocotyl cuttings, planting media, and PGR on the SQ of *Kandelia candel* seedlings

Hypocotyl cutting (H)	Planting media (M)	Plant growth regulator (G)		
		0 ppm (g0)	10.000 ppm (g1)	15.000 ppm (g2)
Intact hypocotyl (h0)	Mud (m0)	3.89 ^{bc}	4.12 ^{ab}	3.45 ^e
	Mud + sand (m1)	4.29 ^a	3.75 ^{cd}	3.75 ^{cd}
	Mud + sand + compost (m2)	3.89 ^{bc}	3.54 ^{de}	4.04 ^{ab}
The top part of hypocotyl (h1)	Mud (m0)	2.03 ^f	1.68 ^{hijk}	1.97 ^{fg}
	Mud + sand (m1)	1.69 ^{ghijk}	1.86 ^{fgh}	1.88 ^{fgh}
	Mud + sand + compost (m2)	1.92 ^{fgh}	1.47 ^{ijklm}	1.71 ^{ghijk}
The bottom part of hypocotyl (h2)	Mud (m0)	1.72 ^{ghij}	1.36 ^{lm}	1.56 ^{ijkl}
	Mud + sand (m1)	1.80 ^{fghi}	1.42 ^{klm}	1.57 ^{ijkl}
	Mud + sand + compost (m2)	1.49 ^{ijklm}	1.30 ^{lm}	1.24 ^m

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

Table 9. The DMRT test of interaction among hypocotyl cuttings, planting media, and PGR on the DQI of *Kandelia candel* seedlings

Hypocotyl cutting (H)	Planting media (M)	Plant growth regulator (G)		
		0 ppm (g0)	10.000 ppm (g1)	15.000 ppm (g2)
Intact hypocotyl (h0)	Mud (m0)	1.33 ^{bcd}	1.33 ^{bcd}	1.55 ^{ab}
	Mud + sand (m1)	1.47 ^{abc}	1.21 ^{def}	1.58 ^a
	Mud + sand + compost (m2)	1.05 ^{efg}	1.25 ^{cde}	1.02 ^{efg}
The top part of hypocotyl (h1)	Mud (m0)	0.45 ^{klm}	0.70 ^{hij}	0.69 ^{hijk}
	Mud + sand (m1)	0.38 ^m	0.47 ^{ijklm}	0.64 ^{ijkl}
	Mud + sand + compost (m2)	0.38 ^m	0.45 ^{lm}	0.46 ^{ijklm}
The bottom part of hypocotyl (h2)	Mud (m0)	1.02 ^{efg}	0.80 ^{ghi}	0.84 ^{ghi}
	Mud + sand (m1)	0.82 ^{ghi}	0.92 ^g	0.89 ^{gh}
	Mud + sand + compost (m2)	0.86 ^{ghi}	0.98 ^{fg}	0.96 ^g

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

Table 10. The DMRT test of interaction between hypocotyl cuttings with planting media on the height and diameter of shoots of *Kandelia candel* seedlings

Hypocotyl cutting (H)	Planting media (M)	Shoot height	Shoot diameter
Intact hypocotyl (h0)	Mud (m0)	41.85 ^a	5.48 ^a
	Mud + sand (m1)	41.21 ^a	5.10 ^{ab}
	Mud + sand + compost (m2)	38.61 ^a	4.87 ^b
The top part of hypocotyl (h1)	Mud (m0)	18.94 ^b	3.57 ^{cde}
	Mud + sand (m1)	17.61 ^b	3.84 ^{cd}
	Mud + sand + compost (m2)	11.94 ^c	3.42 ^{de}
The bottom part of hypocotyl (h2)	Mud (m0)	18.11 ^b	3.28 ^e
	Mud + sand (m1)	22.89 ^b	3.96 ^c
	Mud + sand + compost (m2)	21.11 ^b	3.20 ^e

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

Table 11. The DMRT test of interaction between hypocotyl cuttings with PGR on the height and diameter of shoots and the shoot-root ratio of *Kandelia candel* seedlings

Hypocotyl cutting (H)	Plant growth regulator (G)	Shoot height	Shoot diameter	Shoot-root ratio
Intact hypocotyl (h0)	0 ppm (g0)	42.46 ^a	5.40 ^a	3.87 ^c
	10,000 ppm (g1)	40.67 ^a	5.14 ^{ab}	4.59 ^{ab}
	15,000 ppm (g2)	38.56 ^a	4.90 ^b	4.77 ^a
The top part of hypocotyl (h1)	0 ppm (g0)	16.89 ^c	3.56 ^d	2.41 ^d
	10,000 ppm (g1)	11.67 ^d	3.20 ^d	2.67 ^d
	15,000 ppm (g2)	19.94 ^{bc}	4.08 ^c	2.41 ^d
The bottom part of hypocotyl (h2)	0 ppm (g0)	23.22 ^b	3.37 ^d	4.51 ^{ab}
	10,000 ppm (g1)	17.33 ^c	3.69 ^{cd}	4.00 ^{bc}
	15,000 ppm (g2)	21.56 ^{bc}	3.38 ^d	4.30 ^{abc}

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

Table 12. The DMRT test of interaction between planting media with PGR on the height and diameter of shoots and the shoot-root ratio of *Kandelia candel* seedlings

Planting media (M)	Plant growth regulator (G)	Shoot height	Shoot diameter	Shoot-root ratio
Mud (m0)	0 ppm (g0)	42.46 ^a	5.40 ^a	3.87 ^c
	10,000 ppm (g1)	40.67 ^a	5.40 ^a	4.59 ^{ab}
	15,000 ppm (g2)	40.67 ^a	4.90 ^b	4.77 ^a
Mud + sand (m1)	0 ppm (g0)	16.89 ^c	3.56 ^d	2.41 ^d
	10,000 ppm (g1)	11.67 ^d	3.20 ^e	2.67 ^d
	15,000 ppm (g2)	19.94 ^{bc}	4.08 ^c	2.41 ^d
Mud + sand + compost (m2)	0 ppm (g0)	23.22 ^b	3.37 ^{de}	4.51 ^{ab}
	10,000 ppm (g1)	17.33 ^c	3.69 ^{cd}	4.00 ^{bc}
	15,000 ppm (g2)	21.55 ^{bc}	3.38 ^{de}	4.30 ^{abc}

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

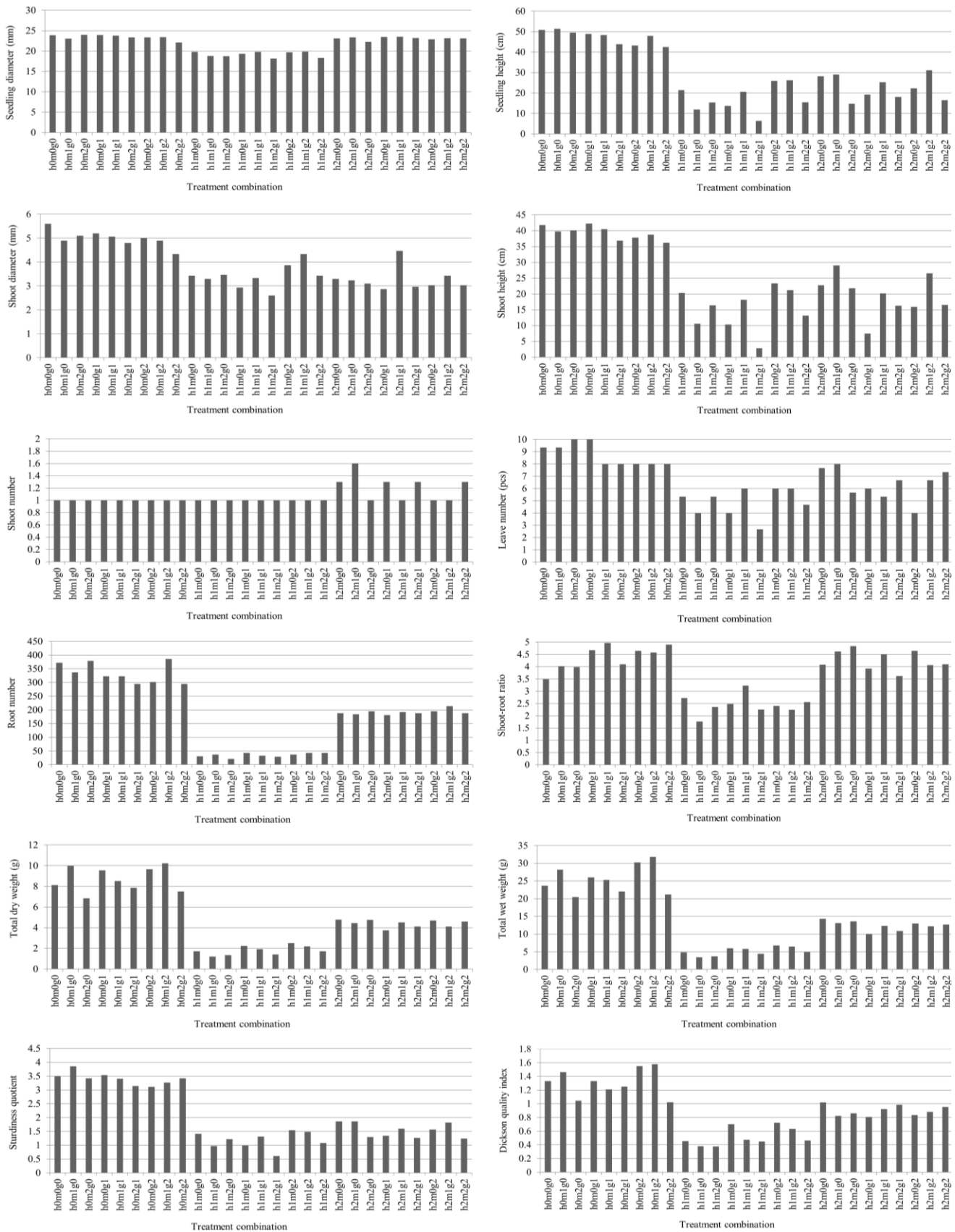


Figure 5. The treatment combination on each parameter of *Kandelia candel* seedlings

Table 13. The DMRT test of the effect of hypocotyl cuttings on the seedling diameter, the root number, the shoot number, and the total dry weight of *Kandelia candel* seedlings

Hypocotyl cutting (H)	Seedling diameter	Root number	Shoot number	Total dry weight
Intact hypocotyl (h0)	17.82 ^a	334.67 ^a	1.00 ^b	12.05 ^a
The top part of hypocotyl (h1)	16.64 ^b	35.22 ^c	1.00 ^b	1.81 ^b
The bottom part of hypocotyl (h2)	16.86 ^b	191.67 ^b	1.22 ^a	4.42 ^b

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

Table 14. The DMRT test of the effect of planting media on the seedling diameter of *Kandelia candel* seedlings

Planting media (M)	Seedling diameter
Mud (m0)	17.61 ^a
Mud + sand (m1)	17.14 ^{ab}
Mud + sand + compost (m2)	16.56 ^b

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

Discussion

The *K. candel* seedlings can grow well in a planting media mixed with sand and mud at pH ± 7 and with water conditions starting from brackish to salty waters (Rahman 2018). A pH value that is too high or too low can inhibit plant growth because several elements are chemically bound (Shivanna and Nagendrappa 2014). The high organic carbon content indicates optimal nutrient plant cycles (Majumder et al. 2018). High nitrogen (N) availability can increase the mangrove's survival and reduce the stress risk (Bai et al. 2016). A lack of N in plants produces a small stem diameter (Sharma 2018).

Plants deficient in phosphorus (P) grow stunted (Das and Bindi 2014). The high potassium (K) concentrations are indicated by green and healthy mangroves naturally without applying fertilizers because the green color indicates that chlorophyll's function and photosynthesis are not disturbed (Tränkner et al. 2018). Plants that lack K are susceptible to attack by pests and diseases (Hu et al. 2017). The high calcium (Ca), magnesium (Mg), and sodium (Na) content can balance soil fertility (Hailu et al. 2015). The high C/N ratio values can moderate the decay rate of organic matter (Wan et al. 2014), and the high CEC value can increase the soil's capacity to provide nutrients (Sidi et al. 2015).

The percentage of live *K. candel* originating from intact hypocotyls in the nursery can reach 100% (Rahman 2018). The success of planting includes two factors: viz. internal and external. Internal factors include hypocotyl food reserves, hormones, hypocotyl size, and hypocotyl viability. Environmental factors include planting media, water availability, temperature, light, and cuttings. The main factor in successful planting is the food reserves stored in the hypocotyl. Long and large hypocotyl indicates large food reserves. Newly planted hypocotyl requires food reserves as a food source to grow before it can carry out photosynthesis (Tomlinson 2016). The height of the seedlings indicates that the division process in the seedling meristem tissue in the apical parts (roots and shoots) has

gone well (Grossnickle and MacDonald 2018). The growth in the height of seedlings from intact hypocotyls is better than hypocotyl cuttings because intact hypocotyls have complete organs compared to cuttings. Hypocotyls include radicle (potential root) and plumule (potential shoot).

The height growth of seedlings from intact hypocotyls began to increase rapidly in the 5th week of observation. In contrast, the growth in the height of seedlings from hypocotyl cuttings began to increase rapidly in the 11th week of observation (Figure 6). West (2014) stated that height growth is faster at the beginning of the plant's age, but at a certain age, the growth in height tends to be slower. Intact hypocotyls have a larger seedling diameter than hypocotyl cuttings. Growth in seedling diameter reflects the activity of meristem tissue in the lateral (cambium). Seedling diameter growth began to increase rapidly in the 7th week of observation. The growth in plant diameter generally forms a sigmoid pattern.

The number of *K. candel* seedlings after four months of planting (Figure 7) showed seedlings from intact hypocotyls had more leaves than seedlings from hypocotyl stems because they have more than one shoot. According to Tomlinson (2016), leaves are very important for plants because they have various functions, such as utilizing light for photosynthesis, CO₂ absorption, and as a place for secretion, filtration, and salt accumulation in mangroves. The number and appearance time of *K. candel* seedling leaves are presented in Table 15. The fastest leaf emergence occurs in seedlings from intact hypocotyl, followed by lower and upper hypocotyl cuttings. The leaves that appear every month consistently increase by two pieces until the fourth month after planting. According to Malabrigo and Pasion (2022), the number of *K. candel* leaves grew consistently after three years of planting.

Roots absorb water and nutrients for the plant body, support the shoots of plants above the ground, and help respiration in mangroves (Batista et al. 2016). Roots formed from the appearance of callus due to injury are called adventitious roots. The arrangement of adventitious roots starts with wound closure and the return of organs with cell differentiation into meristem cells. Meristem cells differentiate into primordia. Furthermore, the hypocotyl tissue breaks down to form roots (Stefens and Rasmussen 2016).

The seedlings from intact hypocotyl had the most noteworthy number of primary, secondary, and tertiary roots. In hypocotyl cuttings, the number of primary, secondary, and tertiary roots of the bottom part is greater than that of the top part of hypocotyl cuttings (Table 16 and Figure 8).

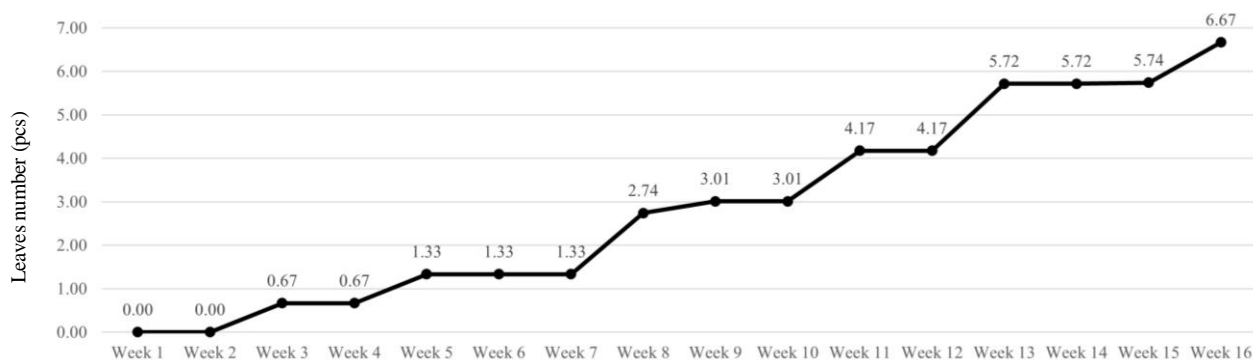


Figure 6. Increasing leaves number of *Kandelia candel* seedlings after 4 months of planting

Table 15. Number and appearance time of *Kandelia candel* seedling leaves

Seedling	Leaves number (pcs)				Appearance time (days)
	May	June	July	August	
Intact hypocotyl (h0)	2	6	8	10	21
The top part of the hypocotyl (h1)	0	2	4	6	60
The bottom part of hypocotyl (h2)	0	2	4	8	53

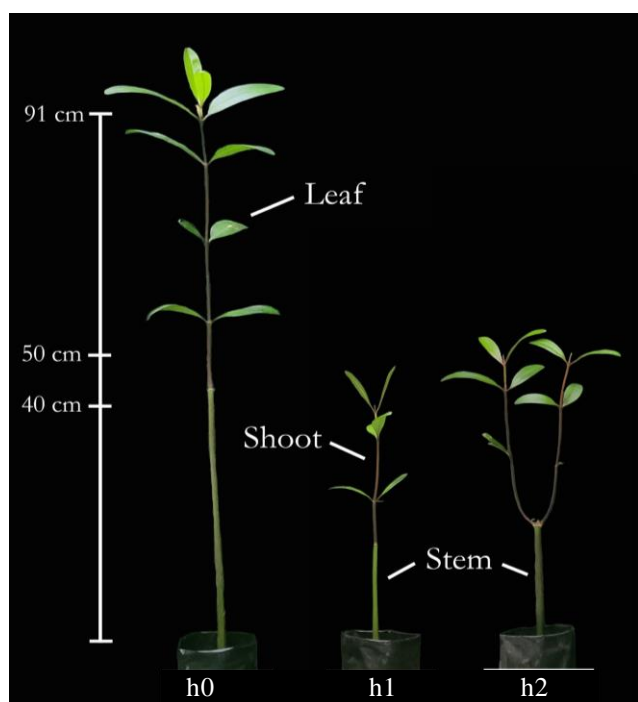


Figure 7. Number of *Kandelia candel* seedlings after 4 months of planting: h0. Intact hypocotyl; h1. The top part of hypocotyl; and h2. The bottom part of the hypocotyl

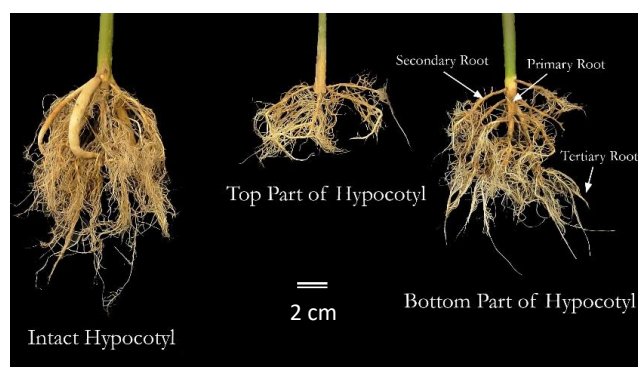


Figure 8. Root number of *Kandelia candel* seedlings after 4 months of planting

Root formation on the bottom hypocotyl cuttings is faster than the upper ones because the radicle on the bottom cuttings is not cut; the hormone auxin influences the ability to form roots on cuttings. Exogenous administration of the auxin hormone in PGR can accelerate root formation (Bellini et al. 2014). This study's administration of exogenous PGR contained active ingredients, namely Indole-3-Butyric Acid (IBA) and Naphthalene Acetate (NAA). IBA and NAA are often used for cuttings because they are more effective and stable in accelerating root formation (Gehlot et al. 2014) than just using IAA as a natural plant auxin (Ren et al. 2023).

Shoots formed from the appearance of callus due to injury are called adventitious shoots. The formation of adventitious shoots is similar to the formation of adventitious roots, only differing in the location and organ of formation, namely the hypocotyl shoot (Stefens and Rasmussen 2016). The formation of intact hypocotyl shoots and upper hypocotyl cuttings is faster than bottom ones because they do not experience pruning. However, the formation of shoots on the bottom hypocotyl at the end of

Table 16. The average roots number of *Kandelia candel* seedlings after 4th months of planting

Hypocotyl seedling (H)	Roots		
	Primary	Secondary	Tertiary
Intact hypocotyl (h0)	1	17	318
The top part of hypocotyl (h1)	0	6	29
the bottom part of hypocotyl (h2)	1	15	174

the observation was more than that of the upper hypocotyl cuttings because the roots were still intact, and cutting resulted in more than one shoot growing. The buds will later develop into perfect leaves.

The total wet weight shows the water content needed by the seedlings, and the total dry weight shows the accumulation of nutrients in the body (Huang et al. 2017). The high value of the shoot-root ratio indicates the dominant growth of the shoots, while a low value indicates the dominant growth of the roots (Takoutsing et al. 2014). The optimum SQ value ranges from 4-5 (Nyoka et al. 2018) and not more than 6 (Dushimimana et al. 2022). Takoutsing et al. (2014) state that a DQI value of more than 0.2 indicates good-quality seedlings.

In conclusion, all combinations of seedling treatments of *K. candel* hypocotyl cuttings yielded a survival rate of 100%. The best growth of hypocotyl cuttings was found in the combination of h2m1g2 treatment (the bottom part of hypocotyl, mud, and sand planting media, also plant growth regulator of 15,000 ppm) with a seedling height of 31 cm, a shoot height of 26.5 cm, a seedling diameter of 15 mm, and a shoot diameter of 3.4 mm, number of leaves 6.7, number of roots 213, the total weight of biomass 12.2 gr, total dry weight 4.1 gr, shoot root ratio 4, SQ 1.6, and DQI 0.9.

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REFERENCES

- Arifanti VB, Novita N, Tosiani A. 2021. Mangrove deforestation and CO₂ emissions in Indonesia. IOP Conf Ser: Earth Environ Sci 874: 012006. DOI: 10.1088/1755-1315/874/1/012006.
- Bai L, Deng H, Zhang X, Yu X, Li Y. 2016. Gibberellin is involved in inhibition of cucumber growth and nitrogen uptake at suboptimal root-zone temperatures. PLoS One 11 (5): e0156188. DOI: 10.1371/journal.pone.0156188.
- Batista RO, Eduardo A, Neto F, Fernanda SD, Eccetti C, Viana CS. 2016. Root morphology and nutrient uptake kinetics by Australian cedar clones. Rev Caatinga 29 (1): 153-162. DOI: 10.1590/1983-21252016v29n118rc.
- Bellini C, Pacurar DI, Perrone I. 2014. Adventitious roots and lateral roots: Similarities and differences. Ann Rev Plant Biol 65: 639-666. DOI: 10.1146/annurev-arplant-050213-035645.
- Das B, Bindi. 2014. Physical and chemical analysis of soil collected from Jaisamand. Unvers J Environ Res Technol 4 (5): 260-264.
- Das SC, Pullaiah, Ashton EC. 2022. Mangroves: Biodiversity, Livelihoods and Conservation. Springer, Singapore. DOI: 10.1007/978-981-19-0519-3.
- Dickson A, Leaf AL, Hosner JF. 1960. Quality appraisal of white spruce and white pine seedling stock in nurseries. For Chron 36: 10-13. DOI: 10.5558/tfc36010-1.
- Dushimimana C, Magomere T, Mulatya J, Vandenebeelee J, Olubayo F, Smaghe G, Werbroeck SPO. 2022. Variation of morphological traits and quality indices of micropropagated *Melia volkensii* Gürke clones before field planting. Forests 13 (2): 337. DOI: 10.3390/fl3020337.
- Gehlot A, Gupta RK, Tripathi A, Arya ID, Arya S. 2014. Vegetative propagation of *Azadirachta indica*: Effect of auxin and rooting media on adventitious root induction in mini-cuttings. Adv For Sci 1 (1): 1-9. DOI: 10.34062/afs.v1i1.1357.
- Grossnickle SC, MacDonald JE. 2018. Why seedlings grow: Influence of plant attributes. New For 49: 1-34. DOI: 10.1007/s11056-017-9606-4.
- Hailu H, Mamo T, Keskinen R, Karlton E, Gebrekidan H, Bekele T. 2015. Soil fertility status and wheat nutrient content in Vertisol cropping systems of central highlands of Ethiopia. Agric Food Secur 4: 19. DOI: 10.1186/s40066-015-0038-0.
- Hamilton SE, Casey D. 2016. Creation of high spatiotemporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). Glob Ecol Biogeogr 25 (6): 729-738. DOI: 10.1111/geb.12449.
- Hu W, Coomer TD, Loka DA, Oosterhuis DM, Zhou Z. 2017. Potassium deficiency affects the carbon-nitrogen balance in cotton leaves. Plant Physiol Biochem 115: 408-417. DOI: 10.1016/j.plaphy.2017.04.005.
- Huang P, de-Bashan L, Crocker T, Kloepper JW, Bashan Y. 2017. Evidence that fresh weight measurement is imprecise for reporting the effect of plant growth-promoting (rhizo) bacteria on growth promotion of crop plants. Biol Fertil Soils 53: 199-208. DOI: 10.1007/s00374-016-1160-2.
- Isnani S, Masjud YI. 2024. Atmospheric carbon dioxide uptake by mangrove trees. Mangrove Watch 1 (1): 27-32. DOI: 10.61511/mangrove.v1i1.2024.657.
- Kusmana C, Hidayat T, Istomo, Rusdiana O. 2018. Growth performance of *Bruguiera gymnorhiza* derived from cut-propagule seedling. Biodiversitas 19 (1): 208-214. DOI: 10.13057/biodiv/d190128.
- Lai HY, Wang Y, Zhang Y, Liang H, Yu S, Zhang K, Zhang L, Shui BN. 2021. Study on the early growth characteristics of *Kandelia candel* plantation in Yanpu Bay, Cangnan, Zhejiang Province. For Res 34 (4): 156-165. DOI: 10.13275/j.cnki.lykxyj.2021.04.019.
- Lavieren HV, Spalding M, Alongi DA, Kainuma M, Godt MC, Adeel Z. 2015. Securing the Future of Mangroves. Institute for Water, Environment and Health, United Nations University, Hamilton.
- Löf M, Madsen P, Metslaid M, Witzell J, Jacobs DF. 2019. Restoring forests: Regeneration and ecosystem function for the future. New For 50: 139-151. DOI: 10.1007/s11056-019-09713-0.
- Majumder SP, Chaitanya AK, Datta A, Padhan D, Badole S, Mandal B. 2018. Dynamics of carbon and nitrogen in agricultural soils: Role of organic and inorganic sources. In: Muñoz MA, Zornoza R (eds). Soil Management and Climate Change. Academic Press, Cambridge, Massachusetts. DOI: 10.1016/B978-0-12-812128-3.00011-2.
- Malabrigo Jr. PL, Pasion BO. 2022. Survival and growth performance of planted *Kandelia candel* (L.) Druce stand in the Philippines. Philipp J Sci 151 (1): 263-273. DOI: 10.56899/151.01.19.
- Marisa H, Sarno, Ridho MR, Indriani DP, Wulansari P. 2020. *Kandelia candel* (L.) Druce Reproductive Organ Phenology, in Berbak and Sembilang National Park, South Sumatra. IOP Conf Ser: Earth Environ Sci 550: 012005. DOI: 10.1088/1755-1315/550/1/012005.
- Méndez-Alonzo R, Moctezuma C, Ordoñez VR, Angeles G, Martínez AJ, López-Portillo J. 2015. Root biomechanics in *Rhizophora mangle*: Anatomy, morphology and ecology of mangrove's flying buttresses. Ann Bot 115 (5): 833-840. DOI: 10.1093/aob/mcv002.
- Ministry of Environment and Forestry (MoEF). 2021. National Mangrove Map. Working Group for Updating National Mangrove Map, Ministry of Environment and Forestry of the Republic of Indonesia, Jakarta. [Indonesian]
- Nugraha LA, Kusmana C, Hartoyo APP. 2022. Utilization of *Kandelia candel* (L.) Druce and hypocotyl cutting seedling for mangrove rehabilitation in Indonesia. IOP Conf Ser: Earth Environ Sci 1109: 012092. DOI: 10.1088/1755-1315/1109/1/012092.
- Nyoka BI, Kamanga R, Njoloma J, Jannadass R, Mng'omba S, Muwanje S. 2018. Quality of tree seedlings produced in nurseries in Malawi: An assessment of morphological attributes. For Trees Livelihoods 27 (2): 103-117. DOI: 10.1080/14728028.2018.1443027.
- Patra JK, Mishra RR, Thatoi H. 2020. Biotechnological Utilization of Mangrove Resources. 1st Edition. Academic Press, Cambridge.
- Prodan M. 1968. Forest Biometrics. Pergamon Press, London.
- Racey GD, Glerum C, Hutchison RE. 1983. The practicality of top-root ratio in nursery stock characterization. For Chron 59 (5): 240-243. DOI: 10.5558/tfc59240-5.
- Rahman MM. 2018. Enrichment of mangrove ecosystems through *Kandelia candel* (L.) Druce species in the Sundarban Mangrove Forest of Bangladesh. Intl J Bus Soc Sci Res 6 (4): 1-8.
- Ren M, Mao G, Zheng H, Wang W, Tang Q. 2023. Growth changes of tomato seedlings responding to sodium salt of α -naphthalene acetic

- acid and potassium salt of fulvic acid. *Sci Rep* 13 (1): 4024. DOI: 10.1038/s41598-023-31023-x.
- Rugayah, Yulita KS, Arifiani D, Rustiami H, Girmasnyah D. 2017. *Tumbuhan Langka Indonesia: 50 Jenis Tumbuhan Terancam Punah*. LIPI Press, Jakarta. [Indonesian]
- Sarno, Ridho MR, Absori A, Kadarisman R. 2020. Konservasi Mangrove: Distribusi, Fenologi, dan Rehabilitasi *Kandelia candel* di Taman Nasional Sembilang. ZSL Indonesia, Bogor. [Indonesian]
- Sharma B. 2018. Chemical analysis of soil of pandoga sub watershed with the seasons in Una (H.P), India. *Intl J Res Rev* 5 (10): 22-27.
- Shettar AK, Vedamurthy AB. 2017. Evaluation of antidiabetic potential of *Kandelia candel* and *Rhizophora apiculata* an in vitro approach. *J Pharm Sci Res* 8 (6): 2551-2559. DOI: 10.13040/IJPSR.0975-8232.8(6).2551-59.
- Shivanna AM, Nagendrappa G. 2014. Chemical analysis of soil samples to evaluate the soil fertility status of selected command areas of three tanks in Tiptur Taluk of Karnataka, India. *IOSR-JAC* 7 (11): 1-5. DOI: 10.9790/5736-071110105.
- Sidi N, Aris AZ, Talib SN, Johan S, Yusoff TST, Ismail MZ. 2015. Influential factors on the cation exchange capacity in sediment of Merambong Shoal, Johor. *Procedia Environ Sci* 30: 186-189. DOI: 10.1016/j.proenv.2015.10.033.
- Srikanth S, Lum SKY, Chen Z. 2016. Mangrove root: Adaptations and ecological importance. *Trees* 30: 451-465. DOI: 10.1007/s00468-015-1233-0.
- Stefens B, Rasmussen A. 2016. The physiology of adventitious roots. *Plant Physiol* 170 (2): 603-617. DOI: 10.1104/pp.15.01360.
- Takoutsing B, Tchoundjeu Z, Degrande A, Asaah E, Gyau A, Nkeumoe F, Tsobeng A. 2014. Assessing the quality of seedlings in small-scale nurseries in the Highlands of Cameroon: The use of growth characteristics and quality thresholds as indicators. *Small-Scale For* 13: 65-77. DOI: 10.1007/s11842-013-9241-7.
- Thompson BE. 1985. Seedling morphological evaluation: What you can tell by looking. In: Duryea ML (eds). *Evaluating Seedling Quality: Principles, Procedures, and Predictive Abilities of Major Tests*. Proceedings of the workshop of Forest Research Laboratory of the Oregon State University.
- Tomlinson PB. 2016. *The Botany of Mangroves*. Cambridge University Press, New York. DOI: 10.1017/CBO9781139946575.
- Tränkner M, Tavakol E, Jáklí B. 2018. Functioning of potassium and magnesium in photosynthesis, photosynthate translocation and photoprotection. *Physiol Plant* 163 (3): 414-31. DOI: 10.1111/ppl.12747.
- Wan X, Huang Z, He Z, Yu Z, Wang M, Davis MR, Yang Y. 2014. Soil C:N ratio is the major determinant of soil microbial community structure in subtropical coniferous and broadleaf forest plantations. *Plant Soil* 387: 103-116. DOI: 10.1007/s11104-014-2277-4.
- West PW. 2014. *Growing Plantation Forest*. Springer, Cham. DOI: 10.1007/978-3-319-01827-0.
- Wilda R, Hamdan AM, Rahmi R. 2020. A review: The use of mangrove for biomonitoring on aquatic environment. *IOP Conf Ser: Mater Sci Eng* 980: 012083. DOI: 10.1088/1757-899X/980/1/012083.
- Zhang M, Wang Y, Tian K, Tian J, Sun P, Shui B. 2019. Changes in the ecological niche and functional groups of macrozoobenthos before and after the planting of *Kandelia candel* in Yanpu Bay, Zhejiang. *J Fish Sci China* 26 (5): 949-958. DOI: 10.3724/SP.J.1118.2019.18421.
- Zhang X, Chua VP, Cheong H-F. 2015. Hydrodynamics in mangrove prop roots and their physical properties. *J Hydro-Environ Res* 9 (2): 281-294. DOI: 10.1016/j.jher.2014.07.010.