Plant Research Journal, 02(01), 36-49 (2026)

RESEARCH ARTICLE – PLANT PROPAGATION

Effect of Indole-3-butyric acid and Jasmonic acid on rooting ability of *Dombeya wallichii* (Lindl.) Benth. & Hook. fil

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Received: 14-04-2026 / Accepted: 12-05-2026 / Published: 13-05-2026

Abstract

This study aimed to investigate the role of plant growth regulators indole-3-butyric acid (IBA) and Jasmonic acid (JA) on the rooting of stem cuttings of *Dombeya wallichii*, popular for their aesthetic and medicinal purposes. The semi-hardwood cuttings were treated with different concentrations of the IBA (10, 20 µM) and/or JA (5, 10 µM) alone or in combinations. The control cuttings were simultaneously treated with water and planted in plastic pots filled with an equal proportion of soil and compost. The results of the experiment suggested that all morphological parameters of the plant did not respond when treated with IBA and JA alone. The maximum increase in all parameters such as highest number of buds (12), leaf length (6.7 cm), leaf width (6.6 cm), number of leaves (14), number of branches (15), shoot length (23 cm), root length (10 cm), fresh weight of shoot (16.3 g), dry weight of shoot (4.6 g), fresh weight of root (2.05 g) and dry weight of root (1.57 g) was recorded when IBA and JA used in combination (10 µM IBA and 5 µM JA). The vigor and survival of the rooted cuttings were optimized and consistent. So, the present research work demonstrated an efficient method for the mass production of plants through vegetatively rooted cuttings to meet the market demands.

Keywords: *Dombeya wallichii*, Growth, Indole-3-butyric acid, Jasmonic Acid, Rooting of cuttings

Key message: IBA is a strong plant growth regulator for rooting in *Dombeya wallichii*.

Abbreviations: IAA Indole-3-acetic acid, **IBA** Indole-3-butyric acid, **JA** Jasmonic acid, **MJ** Methyl Jasmonat, **SA** Salicylic Acid

1. Introduction

Dombeya, a genus within the Malvaceae family, is predominantly found in the paleotropical regions of the world (Tropical Plant Database). The genus *Dombeya* was named after the 18th century by botanist J. Dombey (Idowu et al., 2023). It encompasses of 206 species, with 173 exclusively inhabiting the Islands of Madagascar and Comoros (Skema, 2014). *D. wallichii* (Lindl.), among the genus, found its way to Brazil where it successfully acclimatized to similar tropical conditions. This species typically grows into a shrub or small tree, ranging from 3-9 m in height. It develops expensive, dense canopies and follows a perennial life cycle, blooming during the fall and winter seasons. Its flowering peak occurs predominantly between June and July, subject to variations based on location and prevailing climatic factors (Rocha, 2010). *D. wallichii* possesses floral traits, including color, scent, and nutritional offerings like nectar and pollen, aimed at attracting a diverse array of floral visitors, thereby ensuring successful pollination (Puentes et al., 2019).

The genus *Dombeya* has great importance as a horticultural plant. *D. wallichii*, an exotic plant, is widely cultivated in various regions of Brazil for ornamental purposes. *Dombeya* is reportedly used as a remedy for stomach ailments in Thailand (Tangjitman et al., 2015). Many species of this plant are also useful for their medicinal importance in treating different ailments. The species like *D. rotundifolia* is utilized in traditional medicine to address heart conditions, alleviate nausea in pregnant women, treat intestinal ulcers, headache, stomach issues, hemorrhoids, diarrhea, dyspepsia, and to expedite the onset of labor (Olawuwo et al., 2022). Other species like, *D. buettneri* are medicinal plants from Africa traditionally used to treat infectious diseases. Essential oils extracted from *D. buettneri*, have antimicrobial properties to kill or inhibit infectious agents.

Today, these oils are fundamental components in numerous industrial products, such as perfumes, foods, beverages, and a wide range of biopharmaceuticals (Paul, 2011; Ju et al., 2022; Idowu et al., 2023). The leaves of *D. burgessiae* are used to cure leprosy and malaria, and its roots are used to treat stomach and sugar-related issues (Kazeem and Tom 2016).

The plant is grown through both sexual and asexual methods. Asexual reproduction or vegetative propagation is a practical method to preserve specific traits in plants that might be lost through sexual reproduction (Awotedu, 2021). It is a method to prevent the extinction of the species (Oseni et al., 2018). It is easier and faster than sexual reproduction for some species, allowing for the mass production of genetically identical copies of selected plants (Megersa, 2017). The most widely known propagation technique is cutting, as it is both cost-effective and highly successful (Roberto and Colombo, 2020). Stem cuttings can produce large, uniform quantities of plants, but they often have low success rates due to challenges with rooting and growth (Judd et al., 2015). The rooting success of stem cuttings varies by plant species; some root readily, while others remain stubborn even with the application of growth regulators (Kumar, 2022).

Plant hormones, such as auxins, are crucial for plant growth, particularly in lateral root formation and root gravity response. The success of rooting in cuttings is influenced by several factors including the species and cultivar, the condition of the cutting wood, the type of cuttings (such as hardwood, semi-hardwood, softwood, and herbal cuttings), the season, and other variables (Sandhya et al., 2022). Auxin affects the speed and enhances the percentage of rooting in stem cuttings. IBA is the most effective in promoting root initiation and adventitious root production in stem cuttings (Kaushik and Shukla, 2020). The promoting effect of IBA on rooting is primarily due to its conversion to IAA within plant tissue. However, while IAA is essential for the rooting process, it is quickly oxidized by peroxidases in the plant. In contrast, IAA derived from IBA is not oxidized by peroxidases and remains at the base of the cutting (Abu-Zahra et al., 2012).

The other growth regulator Jasmonic acid affects various aspects of plant growth and development, including the promotion of flower and fruit development, the induction of tuberization and tendril coiling, the inhibition of seed and pollen germination, and the restriction of root growth, among other processes (Sohn, 2022). Low concentrations of JA promote the formation of adventitious roots on cuttings (Cai et al., 2023; Ali et al., 2024). JA-auxin interactions significantly impact a wide range of developmental processes in plants, including seed development and germination, root growth, flower development, seedling growth, tuber formation, and senescence (Xu et al., 2020).

The main objective of the study was to produce the *Dombeya* plant at large scale. As the genus *Dombeya* is native to Africa and serves multiple purposes beyond their medicinal uses, making them more susceptible to extinction compared to single- use species. It is highly valued for its aesthetic qualities as an ornamental plant that is grown for aesthetic effects in landscape or garden designs. Therefore, the demand for the cultivation of this plant is increasing day by day. Thus, protecting and storing this valuable plant is crucial to consistently meet market demands. Therefore, conservation of this species at a large scale can be made possible by growing them asexually with the application of growth regulators for the betterment of our society, country, and the world.

2. Materials and Methods

In the present study, plant growth regulators were applied to observe the rooting ability of stem cuttings of *D. wallichii*. The experiment was conducted from December 2023 to May 2024.

2.1 Procurement of Plant Material

The plant material utilized for this experiment comprised freshly harvested cuttings obtained from the Botanical Garden, Institute of Botany, University of the Punjab, Lahore. Pakistan.

2.2 Soil preparation

The growth medium used for this experiment was the well-drained garden soil. The soil was sieved to remove the straws and stones and then finely ground to pass from the sieve of 5 mm diameter. Compost was also added to it. The proportion of compost and soil used as a growing medium in plastic pots was 1:1. Five to ten small holes were made at the base of each pot (pot size: 9cm length & 11cm width) for drainage and aeration. Then soil was filled equally in each pot and was watered to full saturation.

2.3 Preparation of stem cuttings

To prepare stem cuttings, healthy and disease-free stem cuttings were carefully selected and separated from the species of *Dombeya* mother plants. The stems were cut to a length of 18 cm, with 2-3 nodes, and all leaves were removed. There were 27 cuttings utilized for each treatment. The prepared cuttings were then immersed for about one hour in beaker containing water to prevent drying, with 2.5 to 5 cm of their basal portion submerged before planting in the pots.

2.4 Preparation of stock and working solutions

The growth hormones used in this experiment were the indole-3-butyric acid (IBA) and Jasmonic acid (JA). Therefore, stock solutions of 1mM of IBA and JA were prepared in 100 ml solution, and then from these stock solutions, working solutions of 10 and 20 µM IBA and 5 and 10 µM JA were prepared and stored at 4 ℃ till its use.

The cuttings were dipped in a 10 ml solution of different concentrations of IBA and JA for 30 mins. The following nine treatments were used for this purpose: 1) Control (only water), 2) 5 µM JA, 3) 10 µM JA, 4) 10 µM IBA, 5) 20 µM IBA, 6) 10 µM IBA and 5 µM JA, 7) 10 µM IBA, and 10 µM JA, 8) 20 µM IBA + 5 µM JA, 9) 20 µM IBA + 10 µM JA.

The experiment was carried out in a fully controlled environment (Relative humidity level around 80%, Temperature range of 18 ℃ – 24 ℃) of a glasshouse located at the University of the Punjab, Lahore, using a complete randomized design.

2.5 Manual thinning

Regular manual weeding was performed to prevent any interference with the growth of the experimental plants. The soil was often irrigated by checking the moisture level of the soil. Application as a fungicide, i.e., spray of Hydrogen peroxide (H_2O_2) was also used twice a week to remove any contaminants.

2.6 Experimental observations

The cuttings were monitored for a period of 120 days. Subsequently, 9 cuttings were randomly selected from each of the 9 pots for collecting data for various growth parameters. The cuttings were carefully removed from the soil in each plot, ensuring the roots remained intact. The base of each cutting was delicately washed in a bucket of clean water to avoid any damage to the roots.

2.7 Data collection

Data was collected based on morphological parameters. The number of buds per plant for each treatment was counted by observing the buds on plants at the onset of the emergence of the first bud. Data regarding the number of buds was collected after one week of planting. In each treatment, the total number of buds was counted, and their mean was also calculated. The total number of sprouts per plant was collected by counting the number of sprouts that emerged from the buds. Data was collected after 15 days of planting (15 DAP). The mean of total number of sprouts was calculated in each treatment and then the graph was plotted. The number of leaves per plant was recorded and then leaves of all three replicates of each treatment were recorded, and their mean was calculated and compared with other replicates of other treatments to observe the maximum number of leaves per plant. Leaf Area (cm^2), the length and width of leaves in each replicate were measured using a meter rod by using the following formula.

Leaf Area = 0.498 (LL x LW) + 0.054
where LL represents "leaf length," and LW represents "leaf width"

The number of side branches per plant was counted, and then the total number of branches of all three replicates of each treatment was recorded, and its mean was calculated and subsequently compared with other replicates of all treatments to observe the maximum number of branches produced on each treatment. The graph regarding the number of side branches was plotted against all the treatments. The length of shoots for each treatment was recorded in centimeters from the plant base to its tip using a meter rod during harvesting. Furthermore, after uprooting the plants, root length was also measured in centimeters using a meter rod.

The fresh weight of both shoots and roots from each replicate was determined by individually weighing them using an electric balance. Subsequently, the mean values were recorded. The fresh plants were subjected to drying in an oven at 120°C for 48 hours. Their weight was initially measured, followed by further drying for an additional 24 hours until a constant weight was achieved. Subsequently, the mean value was calculated.

2.8 Statistical Analysis

The data collected was analyzed using SPSS version 20.0, and comparisons of mean values were conducted employing Duncan's multiple range tests, with a significance level established at $P \leq 0.05$.

3. Results

3.1 Number of buds per plant

The data regarding the number of buds per plant is presented in Figure 1A. The results of the experiment showed a significant increase in the number of buds with JA and IBA as compared to T1 control. A significant increase in the number of buds (7) was observed by T5 as compared to T2 (3.7), T3 (4) and T4 (3). Moreover, this increase was further upregulated in plants that received the combined treatment of JA + IBA. The highest (12) number of buds was observed in T6 as compared to T5, while there was a non-significant difference between the number of buds in T7 (6) and T8 (6) when growth regulators were applied in combinations.

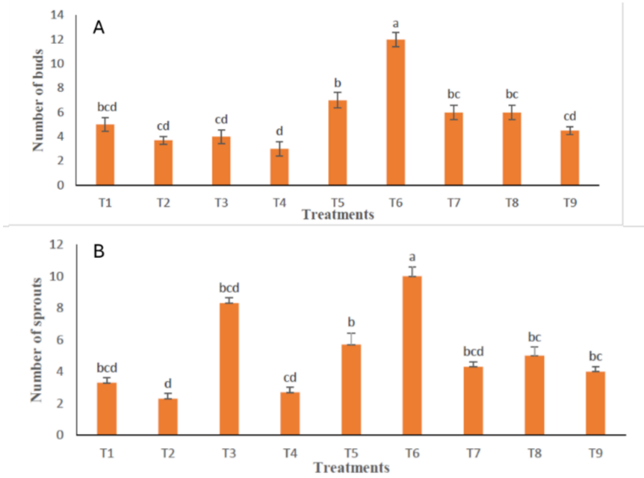

Figure 1. Effect of IBA and/or JA on number of buds per plant of *Dombeya wallichii*. **A)** Number of buds, **B)** Number of sprouts. T_1 = Control, T_2 = 5 µM JA, T_3= 10 µM JA, T_4 = 10 µM IBA, T_5 = 20 µM IBA, T_6 = 10 µM IBA + 5 µM JA, T_7 = 10 µM IBA + 10 µM JA, T_8 = 20 µM IBA + 5 µM JA, T_9 = 20 µM IBA + 10 µM JA. Different letters a, b, c..., represent significantly different results among different treatments as determined by Duncan's multiple range test (DMRT) $p < 0.05$.

3.2 Number of sprouts per plant

Figure 1B presents the number of sprouts per plant. The results revealed that an increase in the number of sprouts was observed in those plants that were treated with growth regulators as compared to control (3.3). A significant increase in the number of sprouts was reported in T3 (8.3) and T5 (5.7) when growth regulators were applied alone but in higher concentrations than T2 (2.3) and T4 (2.7). Moreover, the maximum increase in the number of sprouts was recorded in T6 (10) as compared to T7 (4.3), T8 (5), and T9 (4) when IBA and JA were supplemented together in different combinations (Figures 2, 3, 4, 5).

3.3 Number of leaves

The data regarding number of leaves is presented in Figure 6A. A significant increase in the number of leaves was observed when the basal ends of the cutting were treated with either JA or IBA alone or in combinations as compared to the control. Moreover, the number of leaves increased significantly in T3 (11) and T5 (12), where the growth regulators were applied alone, but in higher concentrations, the number of leaves was significantly reduced in T2 (5) and T4 (5).

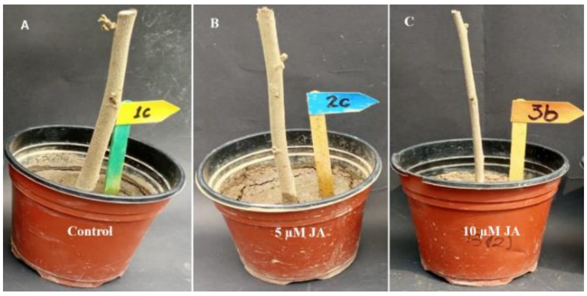

Figure 2. Showing sprouts on stem cuttings of *D. wallichii* treated with different concentrations of JA (A) control, (B) 5 µM JA and (C) 10 µM JA.

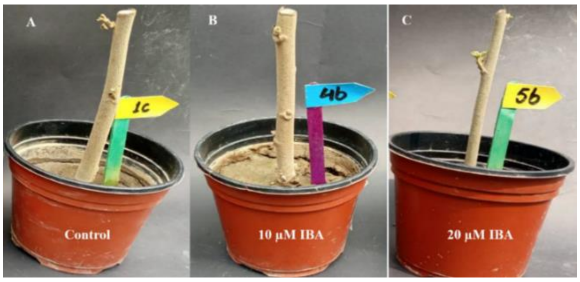

Figure 3. Showing sprouts on stem cuttings of *D. wallichii* treated with different concentrations of IBA (A) control, (B) 10 µM IBA and (C) 20 µM IBA.

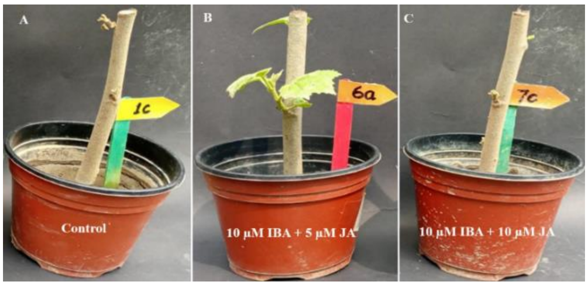

Figure 4. Showing sprouts on stem cuttings of *D. wallichii* treated with different concentrations of IBA and JA (A) Control, (B) 10 µM IBA + 5 µM JA, (C) 10 µM IBA + 10 µM JA.

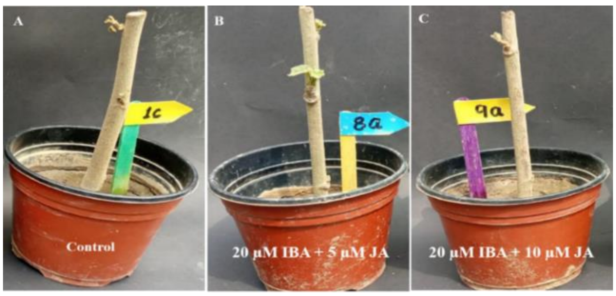

Figure 5. Showing sprouts on stem cuttings of *D. wallichii* treated with different concentrations of IBA and JA (A) Control (B) 20 µM IBA + 5 µM JA, (C) 20 µM IBA + 10 µM JA. Data was collected from 10 replicates.

Further, a maximum number of leaves was observed in T6 (14) followed by the presence of 13 leaves with T7.

3.4 Leaf length

Figure 6 B presents the comparison of the length of the leaves among different treatments. The graph revealed that a significant increase in the length of leaves was observed when growth regulators IBA and JA were applied in different combinations, as compared to leaf length in control (2 cm). The leaf length was significantly increased in T3 (4.5 cm) and T5 (4.7 cm) than the leaf length in T2 (3 cm) and T4 (3.5 cm) when basal ends of the cuttings were supplied with growth regulators alone and in lower concentration. Maximum length of leaves was observed in T8 (7 cm) followed by the length of the leaves (6.7 cm) from T6. The length of leaves was non-significantly different in response of T6 and T8 while length of the leaves was non-significantly reduced to (5.7 cm) and (5.1 cm) in T7 and T9 respectively as compared to T6 and T8.

3.5 Leaf width

A significant increase in the width of the leaves was observed when the basal ends of the stem cutting were treated with different concentrations of different combinations of growth regulators as compared to the control (2.5 cm). A significant increase in the width of the leaves was recorded in T3 (5 cm) and T5 (4.8 cm) as compared to T2 (2.3 cm) and T4 (3.5 cm). Moreover, a highly significant increase in the width of leaves was recorded in T6 (6.6 cm) and T8 (6.6 cm). The width of the leaves was non-significantly different in the case of T5 (4.8 cm) and T9 (4.6 cm) (Figure 6 C).

3.6 Leaf area

The results of leaf area were significantly higher with growth regulators applied in combinations, while the minimum leaf area was observed in the plant without treatment (2.6 cm^2) in the control (Figure 6 D). However, leaf area was significantly increased in the case of T3 (11.1 cm^2) and T5 (11.1 cm^2) when IBA and JA were applied separately in higher concentrations as compared to the leaf area of (3.6 cm^2) and (5.2 cm^2) in

T2 and T4, respectively. The leaf area of T9 (12 cm^2) was non-significantly different from T3 and T5.

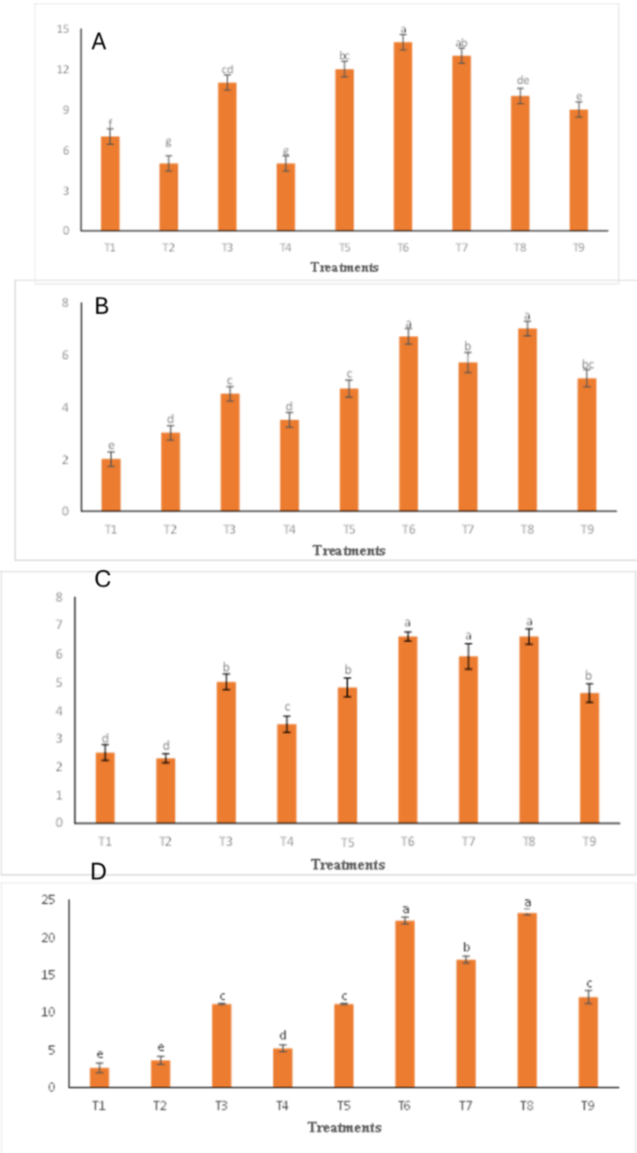

Figure 6. Effect of IBA and/or JA on number of leaves (A), leaf length (cm, B), leaf width (cm, C), leaf area (cm^2, D) per plant of *D. wallichii*. T_1 = Control, T_2 = 5 µM JA, T_3= 10 µM JA, T_4 = 10 µM IBA, T_5 = 20 µM IBA, T_6 = 10 µM IBA + 5 µM JA, T_7 = 10 µM IBA + 10 µM JA, T_8 = 20 µM IBA + 5 µM JA, T_9 = 20 µM IBA + 10 µM JA. Different letters a, b, c…, represent significantly different results among different treatments as determined by Duncan's multiple range test (DMRT) p < 0.5.

Moreover, the maximum and a significant increase in leaf area of (23.2 cm^2) was recorded in T8 followed by the leaf area of (22.2 cm^2) from T6 when JA was applied in combinations but in lower concentrations.

3.7 Number of side branches

A significant increase in number of side branches was observed in those plants that were treated with the combined application of growth regulators as compared to control (Figure 7 A). The leaf area was significantly higher in case of T5 (14) as compared to T2 (7), T3 (9) and T4 (5). The maximum number of side branches was recorded in T6 (15) with a non-significant difference with T5 and a significant difference with all other treatments when IBA and JA were applied alone or in the form of combinations.

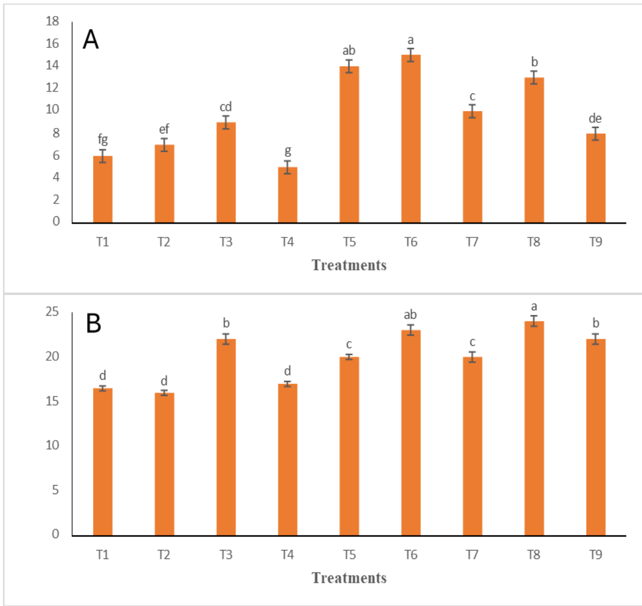

Figure 7. Effect of IBA and/or JA on Side Branches (A) and Shoot Length (B) of *D. burgessiae.* T_1 = Control, T_2 = 5 µM JA, T_3= 10 µM JA, T_4 = 10 µM IBA, T_5 = 20 µM IBA, T_6 = 10 µM IBA + 5 µM JA, T_7 = 10 µM IBA + 10 µM JA, T_8 = 20 µM IBA + 5 µM JA, T_9 = 20 µM IBA + 10 µM JA. Different letters a, b, c…, represent significantly different results among different treatments as determined by Duncan's multiple range test (DMRT) p < 0 5.

3.8 Shoot length

Figure 7 B shows the comparisons of shoot length treated with different concentrations of the growth regulators. The results demonstrated that the interaction between the IBA and JA is a key factor responsible for the significant increase in the shoot length of the plant as compared to the control (16.5 cm). The shoot length significantly increased up to 22 cm in T3 as compared to T2 (16 cm) and T4 (17 cm). Moreover, this increase was further upregulated in T8 (shoot length of 24 cm), which is non-significantly different from T6 (23), while shoot length was significantly different in the case of T7 (20 cm) and T9

(22 cm) when JA was applied in combinations but in higher concentrations (Figures 8, 9).

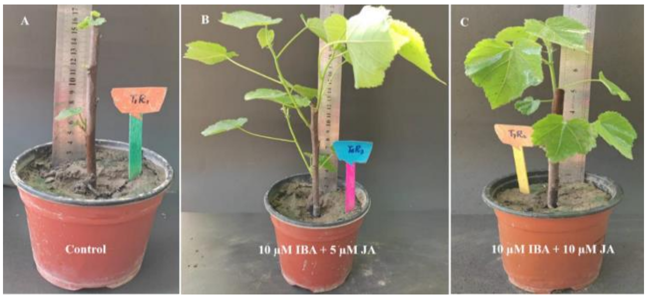

Figure 8. Shoot length of *D. burgessiae* treated with different concentrations of IBA and JA (A) Control, (B) 10 µM IBA + 5 µM JA, (C) 10 µM IBA + 10 µM JA

Figure 9. Shoot length of *D. burgessiae* treated with different concentrations of IBA and JA (A) Control, (B) 20 µM IBA + 5 µM JA, (C) 20 µM IBA + 10 µM JA

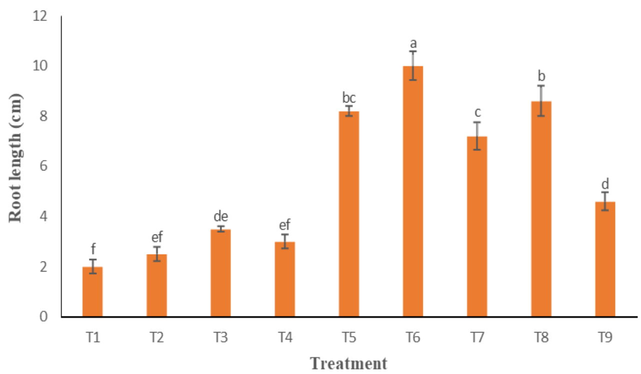

Figure 10. Effect of IBA and/or JA on root length of *D. burgessiae*. T_1 = Control, T_2 = 5 µM JA, T_3= 10 µM JA, T_4 = 10 µM IBA, T_5 = 20 µM IBA, T_6 = 10 µM IBA + 5 µM JA, T_7 = 10 µM IBA + 10 µM JA, T_8 = 20 µM IBA + 5 µM JA, T_9 = 20 µM IBA + 10 µM JA. Different letters a, b, c..., represent significantly different results among different treatments as determined by Duncan's multiple range test (DMRT) $p < 0$

3.9 Root length

The data regarding the root length by analysis of variance (ANOVA) is presented in Figure 10. The results revealed that when JA or IBA were applied in lower concentrations, root length was decreased, and when they were applied in different combinations of specific concentrations, root length was increased as compared to the control (2 cm). A significant increase in root length was observed in T5 (8.2 cm) as compared to T2 (2.5 cm), T3 (3.5 cm) and T4 (3 cm). The root length was non-significantly different in case of T2 and T4. The maximum increase in root length was observed in T6 (10 cm) followed by a length of (8.6 cm) in T8 as compared to the control, while a non-significant difference in root length was recorded in T5 and T8 (Figures 11 A-F).

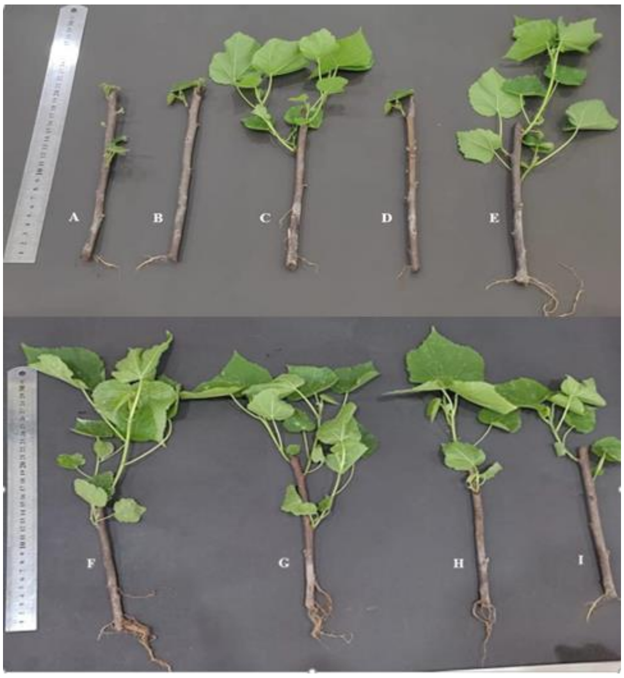

Figure 11. Root length of *D. burgessiae* treated with different concentrations of IBA or JA (A) Control, (B) 5 µM JA, (C) 10 µM JA, (D) 10 µM IBA, (E) 20 µM IBA, (F) 10 µM IBA + 5 µM JA, (G) 10 µM IBA + 10 µM JA, (H) 20 µM IBA + 5 µM JA, (I) 20 µM IBA + 10 µM JA

3.10 Fresh weight of shoot

IBA and JA collectively showed a remarkable increase in fresh weight as compared to the control. The fresh weight of the shoot had no significant difference in case of T2 (9.74 g) and T4 (10.8 g), while a gain in fresh weight of shoots was observed in T3 (15.8 g) and T5 (14.5 g) when growth regulators were applied alone and in higher concentrations. Moreover, a highly significant increase in fresh weight of shoots was observed in T6 (16.3 g) which is non-significantly different with T7 (0.34 g) and T3 (15.8 g) while significantly different with all other treatments of IBA and JA. A non-significant difference in fresh weight of shoots was also observed in T7 (15 g) and T8 (14.8 g) as compared to control (Figure 12 A).

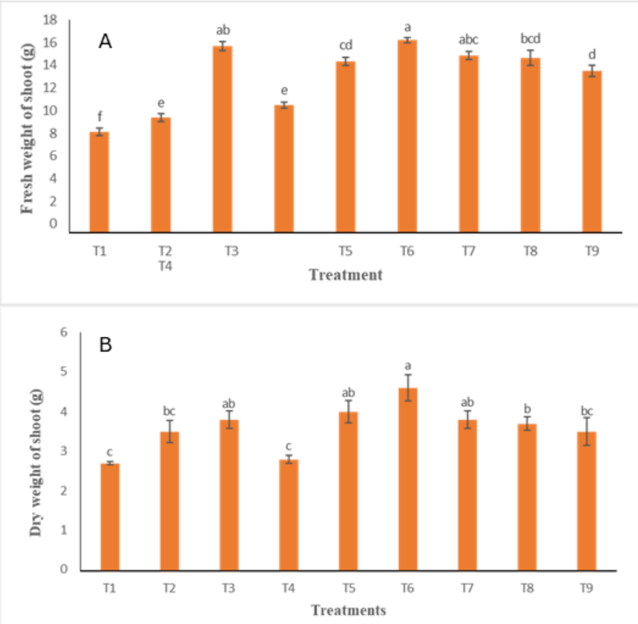

Figure 12. Effect of IBA and/or JA on Fresh Weight (A) and Dry Weight (B) of shoot of *D. burgessiae*. T_1 = Control, T_2 = 5 µM JA, T_3= 10 µM JA, T_4 = 10 µM IBA, T_5 = 20 µM IBA, T_6 = 10 µM IBA + 5 µM JA, T_7 = 10 µM IBA + 10 µM JA, T_8 = 20 µM IBA + 5 µM JA, T_9 = 20 µM IBA + 10 µM JA. Different letters a, b, c, represent significantly different results among different treatments as Duncan's multiple range test (DMRT) p < 0 5.

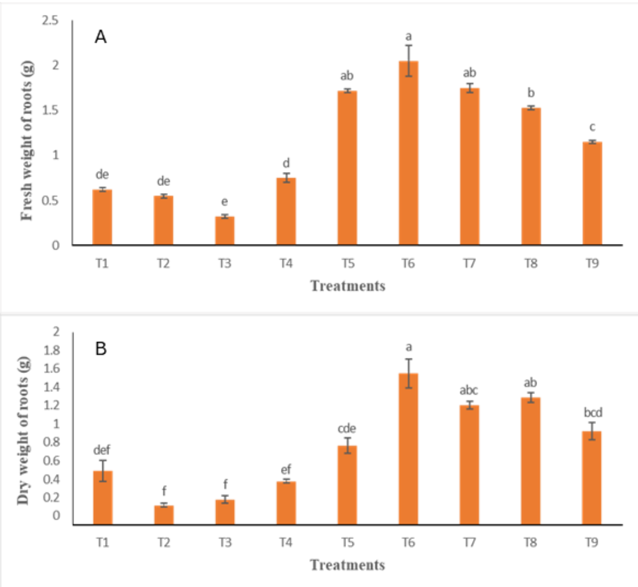

Figure 13. Effect of IBA and/or JA on Fresh Weight (A) and Dry Weight (B) of roots of *D. burgessiae*. T_1 = Control, T_2 = 5 µM JA, T_3= 10 µM JA, T_4 = 10 µM IBA, T_5 = 20 µM IBA, T_6 = 10 µM IBA + 5 µM JA, T_7 = 10 µM IBA + 10 µM JA, T_8 = 20 µM IBA + 5 µM JA, T_9 = 20 µM IBA + 10 µM JA. Different letters a, b, c…, represent significantly different results among different treatments as determined by Duncan's multiple range test (DMRT) p < 0 5.

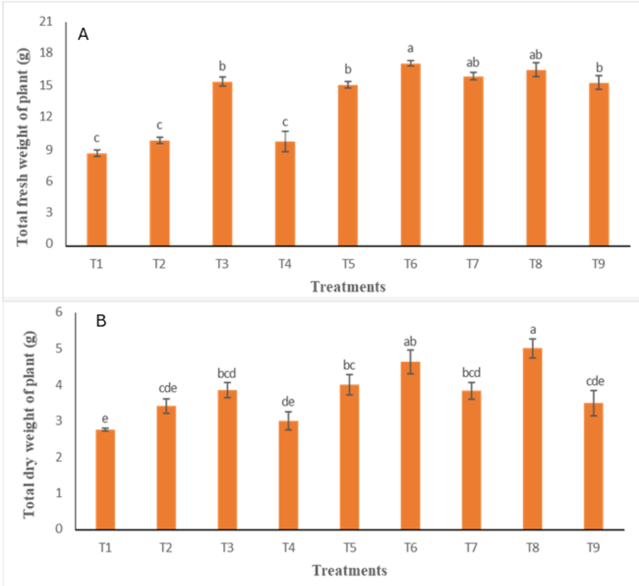

Figure 14. Effect of IBA and/or JA on Total Fresh Weight (A) and Total Dry Weight (B) of plant of *D. burgessiae.* T_1 = Control, T_2 = 5 µM JA, T_3= 10 µM JA, T_4 = 10 µM IBA, T_5 = 20 µM IBA, T_6 = 10 µM IBA + 5 µM JA, T_7 = 10 µM IBA + 10 µM JA, T_8 = 20 µM IBA + 5 µM JA, T_9 = 20 µM IBA + 10 µM JA. Different letters a, b, c…, represent significantly different results among different treatments as determined by Duncan's multiple range test (DMRT) p < 0 5.

3.11 Dry weight of shoot

The data regarding the dry weight of the shoot is presented in Figure 12 B. The dry weight of the shoot decreased in those plants that were treated with lower concentrations of growth regulators, while a significant increase in dry weight of shoots was recorded in T3 (3.8 g) and T5 (4 g) as compared to the control (2.7 g). A non-significant reduction in dry weight of shoots was recorded in T2 (3.5 g) and T4 (2.8 g), which showed less efficiency of growth regulators towards rooting performance when applied exogenously in lower concentrations. Moreover, the maximum increase in dry weight of shoots was observed in T6 (4.6 cm), which is non-significantly different from the dry weight of shoots in T7 (3.8 g) while significantly different from T8 (3.7 g) and T9 (3.5 g). The dry weight of the shoot in T6 was non-significantly different from the dry weight of the shoot in T4.

3.12 Fresh weight of root

The maximum gain in fresh weight of the root was observed in the plants that were treated with the combinations of growth regulators as compared to the control (Figure 13 A). A significant increase in fresh weight of root was observed in T5 (1.72 g) as compared to fresh weight of root in T2 (0.55 g), T3 (0.32 g) and T4 (0.75 g). Fresh weight of roots was reduced in T2, T3 and T4. Moreover, a highly noticeable increase in fresh weight of roots was recorded in T6 (2.05 g) which is non-significantly different from T7 (1.75 g), while significantly different from T8 (1.53 g) and T9 (1.15 g) as compared to T5.

3.13 Dry weight of root

Dry weight of roots was badly affected in the treatments when basal ends of the cuttings were treated with JA alone, either with lower or higher concentrations, as compared to the control (0.56 g). However, in the case of IBA treatment, the dry weight of roots increased up to 0.82 g compared to T2 (0.2 g), T3 (0.26 g) and T4 (0.45 g). Similarly, a highly significant increase in dry weight of roots was recorded in T6 (1.57 g), which is non-significantly different from T7 (1.24 g) while the dry weight of roots was significantly reduced to 0.97 g in T9 as compared to T6 (Figure 13 B).

3.14 Total fresh weight of plant

The interaction between the JA and IBA leads to the maximum gain in fresh weight (Figure 14 A) of the plant when growth regulators were applied in combined treatments as compared to the control (8.7 g). A non-significant increase in total fresh weight of plant was observed in T3 (15.4 g) and T5 (15.1 g), while a non-significant loss in fresh weight of plant was recorded in T2 (9.9 g) and T4 (9.8 g) when growth regulators were applied alone and in lower concentrations. Moreover, a remarkable increase in weight was observed in T6 (17.1 g), which is not significantly different from T7 (15.9 g) and T8 (16.5 g) while a significant loss in weight of the plant was recorded in T9 (15.3 g) as compared to T6.

3.15 Total dry weight of plant

The total dry weight of the plant was reduced in the treatments when the basal ends of the cuttings were treated with only JA, either with lower or higher concentrations, and the maximum dry weight of roots was recorded on the cuttings that were treated with the combined application of IBA and JA, as compared to the control (2.76 g). The total dry weight of the plant was non-significantly increased in T3 (3.85 g) and T5 (4 g), while the weight of plant was reduced in T2 (3.41 g) and T4 (3). Moreover, a maximum increase in dry weight of the plant was recorded in T8 (5 g), which is non-significantly different from T6 and significantly different among all the treatments (Figure 14 B).

Discussion

The trend of asexual propagation is widely practiced to multiply plants with desired traits and maintain their purity for commercial use in many fruit crops. The technique of vegetative propagation has gained popularity in horticulture in recent years. Many horticultural crops that are typically difficult to root can now be rooted more easily using plant growth regulators, appropriate growing media, and optimal propagation conditions.

In the present study, the effect of growth regulators IBA and JA was observed for the rooting and establishment of stem cuttings of *Dombeya* plant. Results of the experiment revealed that IBA or JA were effective in promoting the rooting and other morphological parameters when they were applied alone at their higher concentration. However, when they were applied in combination, JA and IBA significantly enhanced the rooting ability and growth of the plant compared to when used alone. The combined treatment of 10 µM IBA and 5 µM JA showed the best results among all the other concentrations tested during this investigation.

The findings of the current experiment suggest that a higher concentration of IBA (20 µM) produced more buds and sprouts, while opposite results were recorded when stem cuttings were treated with a lower concentration of JA (5 µM). However, the maximum number of buds and sprouts was found in the combined application of growth regulators (10 µM IBA and 5 µM JA). Corresponding results were found by Guchhait et al. (2024) when they worked on the stem cuttings of Citrus plants, and their findings highlighted that higher concentrations of auxins help in buds and sprouts induction as compared to the control treatment. This may be due to a high accumulation of callus formation in cuttings treated with an optimal dose of auxin, leading to the highest percentage of sprouted cuttings. Current findings also highlighted the role of auxin (IBA) at higher concentration (20 µM) for the production of a higher number of side branches, while a significant reduction in side branches was recorded with a lower concentration of JA (10 µM). However, IBA at both lower and higher concentrations in combination with JA significantly increases the number of side branches. These findings coincide with the findings of Akhtar et al., (2015), which illustrated the role of IBA on stem cuttings of Citrus plants resulted in a maximum number of side branches with a higher concentration of IBA.

A remarkable increase in the number of leaves per stem cutting of the *Dombeya* plant was recorded in the treatment with a higher concentration of IBA (20 µM), while a significant reduction in the number of leaves was recorded with a lower concentration of IBA (10 µM) or JA (5 µM). Thus, IBA is the key factor involved in the development of the maximum number of leaves on the cuttings of the plant. This is due to the change in the assimilate partitioning from roots to leaves, due to auxin resulted in increased carbohydrates and chlorophyll content in the leaves, which could be the cause of this effect. It also improves the soluble protein level, hormonal balance, and mineral content of leaves. Further, it could be the effect of the nutrients in the media encouraging root-level growth, which produces more leaves per cutting. These results coincide with the findings of Mehta et al. (2018) on *Punica granatum*, in which auxins at higher concentrations help in the development of leaves on stem cuttings as compared to the control.

From the current study, it was also observed that a higher concentration of IBA (20 µM) was responsible for increased leaf area than the plants treated with lower concentrations of growth regulators, IBA (10 µM) or JA (5 µM). Similar findings were reported by Naji et al. (2015) in the experiment that was conducted on the three hybrids Lily cultivars to observe the expression of growth regulators IBA, BA, and CCC, highlighting the role of IBA at higher concentration for increased leaf area among all plants. This is because auxins play a significant role in the cell wall's flexibility and elasticity and aid in the activation of certain genes that produce RNA, which is necessary for the synthesis of proteins. so that the water potential becomes more negatively oriented, resulting in a decrease in compacting pressure, an increase in water and nutrient material passing through, and an increase in cell size obtained.

Results of the current experiment exposed the adverse effects of JA at a lower concentration (5 µM) for reduced shoot and root length, while a significant increase in shoot and root length was recorded in stem cuttings treated with IBA at a higher concentration (20 µM). Olatunji et al. (2017) reported that auxin plays a crucial role in various root developmental processes, serving as a signal for the division, elongation, and differentiation of root cells. However, a highly significant increase in shoot and root length was observed when IBA (10 µM) and JA (5 µM) were applied together to the basal ends of the stem cuttings. These results coincide with the findings of Fattorini et al. (2010) when they observed the combined effect of growth hormones IBA and Jasmonic acid exogenously on the stem cuttings of the tobacco plant and the results highlighted that JA at lower concentration is effective in root development when applied together with IBA, while antagonistic results were recorded with higher concentration of JA. Pincelli-Souza et al. (2024) reported that IBA is a precursor of auxin that is converted into IAA through a peroxisomal β-oxidation process. JA triggers the conversion of IBA into IAA as in Arabidopsis, resulting in various plant responses, exposing the essential role of IBA in maintaining auxin homeostasis. These chemicals' changes result in the formation of increased root and shoot length in stem cuttings of the plant.

Significant increase was observed in fresh and dry weight of shoots and roots when stem cuttings of Dombeya plant were treated with a combination of growth regulators at lower concentration (10 µM IBA and 5 µM JA) as compared to the application of IBA or JA alone. Similar findings were achieved by Hou et al. (2020) who experimented on *Azalea* cuttings treated with different combinations of growth regulators IBA, NAA and SA. Their findings suggest that compared to the concentration of NAA, the highest shoot and root fresh and dry weight was achieved in treatment with the combined application of IBA and SA. The lower concentration of SA promotes rooting in Azalea cuttings while higher concentration inhibits root development and decreases the fresh and dry weight of the shoot and root. According to Gutierrez et al. (2012), the development of adventitious roots (ARs) is a process influenced by the interaction between auxin and JA. Auxin controls the levels of active JA-Ile by regulating the expression of several GH3 genes, including GH3.3, GH3.5, and GH3.6. The proteins produced by these genes are thought to conjugate JA with amino acids, thereby adjusting the levels of both free JA and JA-Ile. This mechanism favours the development of adventitious roots and then maintains the healthy, fresh, and dry weight of shoots and roots. Thus, it can be concluded that rooting and establishment of stem cuttings of *Dombeya* plant can be increased to a significant level when growth regulators were applied exogenously at a particular concentration of 10 µM IBA and 5 µM JA.

Conclusion

In the current study, successful rooting was achieved in the stem cuttings of the Dombeya plant that was treated with either the application of growth regulators separately but at higher concentration (10 µM JA or 20 µM IBA) or in combined application of growth regulators but at lower concentration (10 µM IBA and 5 µM JA). A highly significant increase in all the parameters studied was achieved by the combined treatment of Indole 3-butyric acid and Jasmonic acid, but at a lower concentration. Thus, interaction between the IBA and JA leads to outstanding results in rooting performance and establishment of stem cuttings of the *Dombeya* plant through vegetative propagation. Through this method, the conservation of difficult-to-root species can be made possible by application of growth regulators, but application of these growth hormones requires special attention towards their concentration to be applied.

Acknowledgements The authors are thankful to the University of Education and Punjab for providing the necessary facilities to accomplish this research work.

Author(s) contribution S.S. Conceptualization, methodology, software, validation, formal analysis and investigation, data curation, writing—original draft preparation, **S.A.K.** writing—review and editing, supervision. All authors have reviewed and approved the manuscript.

Conflict of interest The authors declare no conflict of interest.

Data availability All data supporting the findings of this study are available within the paper. We do not have any research data outside the submitted manuscript file.

Declarations

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Abu-Zahra, T. R., Hasan, M. K., & Hasan, H. S. (2012). Effect of different auxin concentration on virginia creeper (*Parthenocissus quinquefolia*) rooting. World Applied Sciences Journal, 16(1), 7-10.

Akhtar, G., Akram, A., Sajjad, Y., Balal, R. M., Shahid, M. A., Sardar, H., & Shah, S.M. (2015). Potential of plant growth regulators on modulating rooting of *Rosa centifolia*. American Journal of Plant Sciences, 6(05), 659.

Ali, H., Hussain, I., Ali, K., Noor, S., Imtiaz, A., Zeeshan, M., … Sarwar, S. (2024). Effects of growth regulator on invitro propagation of lilium using bulb scale. Pakistan Journal of Biotechnology, 21(2), 339–344. https://doi.org/10.34016/pjbt.2024.21.02.927

Aremu, A. O., & Pendota, S. C. (2021). Medicinal plants for mitigating pain and inflammatory-related conditions: an appraisal of ethnobotanical uses and patterns in South Africa. Frontiers in Pharmacology, 12, 758583.

Ashrafuzzaman, M., & Sarwar, A. K. M. (2021). Species diversity of Sterculiaceae at Bangladesh Agricultural University Botanical Garden and their ethnobotanical uses. Asian Journal of Research in Botany, 5(4), 1-8.

Awotedu, B. F., Omolola, T. O., Akala, A. O., Awotedu, O. L., & Olaoti-Laaro, S. O. (2021). Vegetative propagation: A unique technique of improving plants growth. World News of Natural Sciences, 35, 83-101.

Bhandari, A. J., Patel, R. B., Chawla, S. L., Pavagadhi, D. C., & Patel, B. B. (2015). Effect of plant growth regulators (PGR'S) on vegetative propagation of *Hibiscus rosa-sinensis* L. BIOINFOLET-A Quarterly Journal of Life Sciences, 12(1a), 121-124.

Bożek, M., Denisow, B., Strzałkowska-Abramek, M., Chrzanowska, E., & Winiarczyk, K. (2023). Non-forest woody vegetation: a critical resource for pollinators in agricultural landscapes. Sustainability, 15(11), 8751.

Cai, K., Zhang, D., Li, X., Zhang, Q., Jiang, L., Li, Y., & Zhao, X. (2023). Exogenous phytohormone application and transcriptome analysis provides insights for adventitious root formation in *Taxus cuspidata*. Plant Growth Regulation, 100(1), 33-53.

Chen, H., Lei, Y., Sun, J., Ma, M., Deng, P., Quan, J. E., & Bi, H. (2023). Effects of Different Growth Hormones on Rooting and Endogenous Hormone Content of Two *Morus alba* L. Cuttings. Horticulturae, 9(5), 552.

Druege, U., Franken, P., & Hajirezaei, M. R. (2016). Plant hormone homeostasis, signaling, and function during adventitious root formation in cuttings. Frontiers in Plant Science, 7, 186360.

Elmongy, M. S., Cao, Y., Zhou, H., & Xia, Y. (2018). Root development enhanced by using Indole-3-Butyric Acid and Naphthalene Acetic Acid and associated biochemical changes of in vitro Azalea microshoots. Journal of Plant Growth Regulation, 37, 813-825.

Fattorini, L., Falasca, G., Kevers, C., Mainero Rocca, L., Zadra, C., & Altamura, M. M. (2009). Adventitious rooting is enhanced by methyl jasmonate in tobacco thin cell layers. Planta, 231, 155-168.

Fu, J., Liu, L., Liu, Q., Shen, Q., Wang, C., Yang, P., ... & Wang, Q. (2020). ZmMYC2 exhibits diverse functions and enhances JA signaling in transgenic Arabidopsis. Plant cell reports, 39, 273-288.

Ganesh, J., Hewitt, K., Devkota, A. R., Wilson, T., & Kaundal, A. (2024). IAA- producing plant growth promoting rhizobacteria from *Ceanothus velutinus* enhance cutting propagation efficiency and Arabidopsis biomass. Frontiers in Plant Science, 15, 1374877.

Ghimire, B. K., Kim, S. H., Yu, C. Y., & Chung, I. M. (2022). Biochemical and physiological changes during early adventitious Root formation in Chrysanthemum indicum Linné Cuttings. Plants, 11(11), 1440.

Gonin, M., Bergougnoux, V., Nguyen, T. D., Gantet, P., & Champion, A. (2019). What makes adventitious roots? Plants, 8(7), 240.

Guchhait, P., Varma, S., Banerjee, D., Kumar, S., Halder, R., & Dahiya, A. (2024). Plant growth regulators and rooting media: A viable approach for growth and performance of citrus. Journal of Experimental Agriculture International, 46(5), 366-378.

Gutierrez, L., Mongelard, G., Floková, K., Păcurar, D. I., Novák, O., Staswick, P., & Bellini, C. (2012). Auxin controls Arabidopsis adventitious root initiation by regulating Jasmonic acid homeostasis. The Plant Cell, 24(6), 2515-2527.

Havens, K., Kramer, A. T., & Guerrant Jr, E. O. (2014). Getting plant conservation right (or not): the case of the United States. International Journal of Plant Sciences, 175(1), 3-10.

Hou, P. C., Lin, K. H., Huang, Y. J., Wu, C. W., & Chang, Y. S. (2020). Evaluation of vegetation indices and plant growth regulator use on the rooting of azalea cuttings. Horticultural Brasileira, 38, 153-159.

Idowu, D. O., Aiyelaagbe, O. O., & Idowu, P. A. (2023). Chemical composition and biological activities of volatile oil of the stem of Dombeya buettneri K. Schum. (Sterculiaceae). Scientific African, 20, e01624.

Ju, J., Xie, Y., Yu, H., Guo, Y., Cheng, Y., Qian, H., & Yao, W. (2022). Synergistic interactions of plant essential oils with antimicrobial agents: A new antimicrobial therapy. Critical Reviews in Food Science and Nutrition, 62(7), 1740-1751.

Judd, L. A., Jackson, B. E., & Fonteno, W. C. (2015). Advancements in root growth measurement technologies and observation capabilities for container-grown plants. Plants, 4(3), 369-392.

Kashyap, U., Chandel, A., Sharma, D., Bhardwaj, S., & Bhargava, B. (2021). Propagation of Jasminum parkeri: A critically endangered wild ornamental woody shrub from Western Himalaya. Agronomy, 11(2), 331.

Kaushik, S., & Shukla, N. (2020). A review on effect of IBA and NAA and their combination on the rooting of stem cuttings of different ornamental crops. Journal of Pharmacognosy and Phytochemistry, 9(3), 1881-1885.

Kazeem, M. I., & Tom Ashafa, A. O. (2016). Antioxidant and inhibitory properties of Dombeya burgessiae leaf extracts on enzymes linked to diabetes mellitus. Transactions of the Royal Society of South Africa, 71(2), 167-174.

Khan, F. S., Goher, F., Paulsmeyer, M. N., Hu, C. G., & Zhang, J. Z. (2023). Calcium (Ca^{2+}) sensors and MYC2 are crucial players during jasmonates-mediated abiotic stress tolerance in plants. Plant Biology, 25(7), 1025-1034.

Kumar, A., Choudhary, A., Kaur, H., Sangeetha, K., Mehta, S., & Husen, A. (2022). Physiological and environmental control of adventitious root formation in cuttings. Frontiers in Plant Science, 7(6), 1-24.

Li, S. W. (2021). Molecular bases for the regulation of adventitious root generation in plants. Frontiers in Plant Science, 12, 614072.

Lischweski, S., Muchow, A., Guthörl, D., & Hause, B. (2015). Jasmonates act positively in adventitious root formation in petunia cuttings. BMC plant biology, 15, 1-10.

Liu, G., Zhao, J., Liao, T., Wang, Y., Guo, L., Yao, Y., & Cao, J. (2021). Histological dissection of cutting-inducible adventitious rooting in Platycladus orientalis reveals developmental endogenous hormonal homeostasis. Industrial Crops and Products, 170, 113817.

Masoko, P., Matotoka, M. M., & Mphosi, M. S. (2022). Phytochemical analysis and antibacterial activity of Citrullus lanatus var. citroides (Citron watermelon) fruit and the effect of temperature on the biological activity of the rind. South African Journal of Botany, 150, 1111-1121.

Mazzoni-Putman, S. M., Brumos, J., Zhao, C., Alonso, J. M., & Stepanova, A. N. (2021). Auxin interactions with other hormones in plant development. Cold Spring Harbor Perspectives in Biology, 13(10), a039990.

Megersa, H. G. (2017). Propagation methods of selected horticultural crops by specialized organs. Journal of Horticulture, 4(02).

Mehta, S. K., Singh, K. K., & Harsana, A. S. (2018). Effect of IBA concentration and time of planting on rooting in pomegranate (Punica granatum) cuttings. Journal of Medicinal Plants Studies, 6(1), 250-253.

Naji, D. A., Attiya, H. J., & Askar, H. M. (2015). Effect of plant growth regulators (IBA, BA, and CCC) on some vegetative characters of three hybrid lily cultivars of (Lilium spp. L.). Iraqi Journal of Science, 56(2A), 972-982.

Olatunji, D., Geelen, D., & Verstraeten, I. (2017). Control of endogenous auxin levels in plant root development. International Journal of Molecular Sciences, 18(12), 2587.

Olawuwo, O. S., Famuyide, I. M., & McGaw, L. J. (2022). Antibacterial and antibiofilm activity of selected medicinal plant leaf extracts against pathogens implicated in poultry diseases. Frontiers in veterinary science, 9, 820304.

Oseni, O. M., Pande, V., & Nailwal, T. K. (2018). A review on plant tissue culture, a technique for propagation and conservation of endangered plant species. International Journal of Current Microbiology and Applied Sciences, 7(7), 3778-3786.

Pamfil, D., & Bellini, C. (2011). Auxin control in the formation of adventitious roots. Notulae Botanicae. Horti Agrobotanici Cluj-Napoca, 39(1), 307-316.

Paul, S. (2011) *Trachyspermum ammi* (L.) fruit essential oil influencing on membrane permeability and surface inhibiting food –borne pathogens. Food Control, 22. 725 – 6.

Pincelli-Souza, R. P., Tang, Q., Miller, B. M., & Cohen, J. D. (2024). Horticultural potential of chemical biology to improve adventitious rooting. Horticulture Advances, 2(1), 1-25.

Puentes, S. M., Lopez, J. C., Galhardo, D., Oliveira, J. W., & de Toledo, V. A. A. (2019). Foraging behaviour of Apis mellifera L. and Scaptotrigona bipunctata
on *D. wallichii*flowers in southern Brazil. Agricultural Science, 45, 108085.

Ranjbar, A., & Ahmadi, N. (2016). The effects of IBA and NAA, and rooting media on propagation of miniature rose cuttings (Rosa hybrida). Journal Of Horticultural Science, 30(3), 520-528.

Rasmussen, A., Hosseini, S. A., Hajirezaei, M. R., Druege, U., & Geelen, D. (2015). Adventitious rooting declines with the vegetative to reproductive switch and involves a changed auxin homeostasis. Journal of Experimental Botany, 66(5), 1437-1452.

Rifnas, L. M., Vidanapathirana, N. P., Silva, T. D., Dahanayake, N., Subasinghe, S., Weerasinghe, S. S., & Madushani, W. G. C. (2023). Development of Cutting Propagation Technique for Ornamental Plant Allamanda cathartica (Rukkathana). Journal of Agro-Technology and Rural Sciences, 3(1), 28-33.

Roberto, S. R., & Colombo, R. C. (2020). Innovation in propagation of fruit, vegetable and ornamental plants. Horticulturae, 6(2), 23.

Rocha, J.F. (2010) Anatomy e Histochemistry of the Floral Nectaries of *D. wallichii*(Lindl.) K. Schum. and Dombeya natalensis Sond. (Malvaceae). Revista de Biologia Neotropical, 7, 27-36.

Ruan, J., Zhou, Y., Zhou, M., Yan, J., Khurshid, M., Weng, W., ... & Zhang, K. (2019). Jasmonic acid signaling pathway in plants. International journal of molecular sciences, 20(10), 2479.

Sandhya, S., Mehta, S., Pandey, S., & Husen, A. (2022). Adventitious root formation in cuttings as influenced by genotypes, leaf area, and types of cuttings. Frontiers in Plant Science,33(4), 842469.

Shinde, M. B., Rathod, N. G., Gupta, N. S., Deshmukh, M. S., & Uphade, C. V. (2022). Effect of growth regulators on sprouting and rooting of Bougainvillea hardwood cuttings. The Pharma Innovation Journal, 11(1), 846-850.

Singh, B., Sindhu, S. S., Yadav, H., & Saxena, N. K. (2017). Influence of growth hormones on hardwood cutting of Bougainvillea cv. Dr HB Singh. Chemical Science Review and Letter 6(23), 1903-1907.

Skema, C. (2014). Re-evaluation of species delimitations in Dombeya section Hilsenbergia (Dombeyaceae). Systematic Botany, 39(2), 541-562.

Sohn, S. I., Pandian, S., Rakkammal, K., Largia, M. J. V., Thamilarasan, S. K., Balaji, S., & Ramesh, M. (2022). Jasmonates in plant growth and development and elicitation of secondary metabolites. Frontiers in Plant Science, 13, 942789.

Solgi, M., Taghizadeh, M., and Bagheri, H. (2022). Response of black mulberry onto white mulberry rootstock to stenting (cutting grafting) techniques and IBA concentrations. Ornamental Horticulture. 28, 78–84.

Soliman, W. S., Saad-Eldeen, K., & Gahory, A. A. (2023). An Investigation of Indole Butyric Acid Effects on Growth and Development of Dwarf Bougainvillea. Aswan University Journal of Sciences and Technology, 3(1), 154-163.

Sultana, Z., Akand, M. S. H., Patwary, N. H., Mahbuba, M., Authors, K., & Amin, M. R. (2016). Rooting performance of stem cuttings of three ornamental plants as influenced by growth regulators. International Journal of Natural and Social Sciences, 3(2), 38-45.

Sundararajan, S., Sivakumar, H. P., Rajendran, V., Kumariah, M., & Ramalingam, S. (2023). Adventitious roots in rice, the model cereal: genetic factors and the influence of environmental cues—a mini review. Plant Cell, Tissue and Organ Culture, 154(1), 1-12.

Tangjitman, K., Wongsawad, C., Kamwong, K., Sukkho, T., & Trisonthi, C. (2015). Ethnomedicinal plants used for digestive system disorders by the Karen of northern Thailand. Journal of Ethnobiology and Ethnomedicine, 11, 1-13.

Tropical Plants Database, Ken Fern. tropical.theferns.info. 2026-05-07. <tropical.theferns.info/viewtropial.php?id=Dombeya+burgessiae>

Vielba, J. M., Vidal, N., José, M. C. S., Rico, S., & Sánchez, C. (2020). Recent advances in adventitious root formation in chestnut. Plants, 9(11), 1543.

Wang, M., Xiao, J., Wei, H., & Jeong, B. R. (2020). Supplementary light source affects growth and development of carnation 'Dreambyul'cuttings. Agronomy, 10(8), 1217.

Wang, Y., Mostafa, S., Zeng, W., & Jin, B. (2021). Function and mechanism of Jasmonic acid in plant responses to abiotic and biotic stresses. International Journal of Molecular Sciences, 22(16), 8568.

Winkelmann, T. (2012, July). Recent advances in propagation of woody plants. II International Symposium on Woody Ornamentals of the Temperate Zone, 990 (375-381).

Xu, P., Zhao, P. X., Cai, X. T., Mao, J. L., Miao, Z. Q., & Xiang, C. B. (2020).

Integration of jasmonic acid and ethylene into auxin signaling in root development. Frontiers in Plant Science, 11, 519782.

Zhang, Y., Li, Y., Hassan, M. J., Li, Z., & Peng, Y. (2020). Indole-3-acetic acid improves drought tolerance of white clover via activating auxin, abscisic acid and jasmonic acid related genes and inhibiting senescence genes. BMC Plant Biology, 20, 1-12.

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