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Epicormic Shoot Induction and Rooting of *Tectona grandis* from Branch Cuttings: Influence of Growing Condition and Hormone Application

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Abstract: The purpose of this study was to understand the effect of controlled circumstances and exogenous hormones on epicormic shoot development and rooting ability of teak epicormic shoots obtained from teak branch cuttings. The growing conditions had an effect on physiological and shoot quality parameters with an average of 8 to 10 harvestable shoots per branch cutting. Naphthalene acetic acid (NAA) inhibited the production of epicormic shoots on branch cutting. Rooting percentage increased with increasing IBA concentration, whereas the combinations of indole butyric acid (IBA) and NAA encouraged the callusing. NAA was inhibited either rooting or forming callus in teak cuttings. Shorter and thinner cuttings failed to produce roots as all rooting parameters were lower. The highest rooting percentage (67.40%) was exhibited in the cuttings of diameter sizes 5.50 to 7.00 mm, and the least (45.03%) was in 2.50 to 4.00 mm cuttings.

Keywords: Epicormic shoot, Vegetative propagation, Auxin, Teak, Branch stick cutting

Tectona grandis is perhaps the most well-known tropical timber species grown widely to meet the demand of wood-based industries in the tropics. Teak is a deciduous species, naturally distributed in South Asian Countries with substantial genetic diversity owing to its wide occurrence. The teak plantations managed traditionally for rotation of 60-80 years are no longer well-adapted to the present scenario of demand crisis. Even though teak cultivation in India was geared up in recent decades, productivity is very low (Shahapurmath et al 2016, Chelliah et al 2021, Sasidharan 2021). According to the Food and Agricultural Organization, about 70% of teak logs consumed in India are imported from Africa and Latin America. The low productivity of teak plantations is attributed to low-quality planting material and poor management. Propagation of teak through seeds has limitations because of low germination percentage, failure of teak plantations in flower induction, asynchrony in flowering among the clones, pollination, and fruit set (Vasudeva 2004, Palupi et al 2010, Florence and Mohanadas 2011). The problems with seed production and demand for planting material for rapid expansion of plantations outside the natural forest have encouraged different vegetative propagation methods. Selecting superior parents and rejuvenation by vegetative means is vital for any improvement program. The vegetative propagation of tree species aims to produce exploitable yield earlier than seed-origin plants. Vegetative propagation helps retain physiological age and improve the genetic base through maintaining genetic consistency. Despite several attempts at vegetative propagation, there is little information on the teak's macro-propagation technique through epicormic shoot production from branch stick cuttings. Most vegetative propagation investigations were done on apical shoot cutting, hard-stem cutting, softwood cutting, and grafts, coupled with exogenous growth hormone treatments (Husen 2013, Guleria and Vashisht 2014, Packialakshmi and Sudhagar 2019).

The use of juvenile shoots for plant production has an advantage over the stem cuttings through an improved root system with taproot production, rooting potential, and reduced lignification. The epicormic shoots or mini juvenile cuttings show orthotropic growth by reduced topophysis effect as the presence of shoot apex (Packialakshmi and Sudhagar 2019). In general, juvenile propagules in tree species are produced by either coppicing or girdling the matured tree, which is lethal to the tree. Production of juvenile shoots on stick branch cutting by forced epicormic bud bursting without losing the mother tree is an option. These then can be used for developing a mother-clonal-hedge garden or planting directly after rooting (Pinon et al 2021). This study was designed to investigate the effect of controlled environmental settings and exogenous hormones on the development of epicormic shoots from branch cuttings of teak and its rooting.

MATERIAL AND METHODS

Study site: The study was conducted at the College of Forestry, Kerala Agricultural University, Kerala, India (10°32'N, 76°26'E) from October 2021 to April 2022. The location experiences a warm, humid climate with an average annual rainfall of about 2100 to 2500 mm. The average temperature ranges from 24.4°C to 42.8°C with a relative humidity of 80 to 100%.

Experimental material: Branch cuttings were obtained from the middle to lower portion of the crown from trees located in the College of Forestry, Vellanikkara, Trichur tree garden. Branch cuttings were prepared by removing the side branches and cutting them into pieces of 1.25 to 1.5 m in length and 3 to 5 cm in diameter. Damaged and split ends were avoided to reduce the impairment of dormant buds. The juvenile epicormic shoots produced from branch cuttings in the experiment were used for the rooting experiments. The branch cuttings and epicormic shoot cuttings were treated with carbendazim 50 %WP (2%) for ten minutes to avoid fungal infection.

Experimental Design and Data Collection

Effect of growing condition on growth, production, and physiology of epicormic shoots: Branch cuttings were planted in the mist chamber and in the open to investigate the effect of growing conditions on epicormic shoot yield and quality. A 30-second intermittent mist was employed in the mist chamber at 20-minute intervals (7.00 am to 6.00 pm) to maintain the appropriate humidity. In the open, branch cuttings were manually watered every 2 to 3 hours (8.00 am to 5.00 pm). The weather conditions in both environments were recorded using a portable weather recorder (Table 1). The experiment was laid out with three replications, each replication having five branch cuttings each. The biometric parameters of epicormic shoots such as shoot length (cm), shoot diameter (mm), leaf length (cm), leaf width (cm), and leaf area (cm^2) were measured and recorded. The physiological traits such as Photosynthetic Rate (μmol CO_2 m^{-2} s^{-1}), Canopy Air Temperature Difference (CATD) (°C), Stomatal Conductance (μmol H_2O m^{-2} s^{-1}), and Transpiration Rate (μmol H_2O m^{-2} s^{-1}) were measured for the third leaf from the tip using an IRGA (LI6400 portable photosynthetic system). The total chlorophyll content of leaves was recorded with the help of SPAD. The relative water content (%) of leaves was estimated (Barrs 1968).

Exogenous growth hormone and epicormic shoot production: The prepared branch cuttings (1.25 to 1.5 m in length and 3 to 5 cm in diameter) were planted after treatment with various concentrations (liquid form) of growth hormones (Table 2) and maintained in the mist chamber. The lower cut end of branch cuttings was dipped in the required concentration of plant growth regulator for eight hours. The treated branch cuttings were planted in polybags containing a mixture of soil and coco-coir pith (1:1). Each treatment was laid out as a CRD with three replications with five branch cuttings forming one replication. The total number of live buds (buds with a length of less than 1 cm), sprouts (buds with a length greater than 1 cm), and harvestable shoots (shoots with a length greater than 5 cm) produced during the study period were recorded until the majority of the branch cuttings dried. The biometric parameters of epicormic shoots such as shoot length (cm), shoot diameter (mm), and the number of leaves were recorded.

Effect of growth hormones on rooting of epicormic shoots: The epicormic shoots produced from the branch cuttings were excised at the three to four pair leaf-stage. Immediately after detaching from the main branch, cuttings were immersed in water to avoid desiccation. The 2/3 parts of the leaves were carefully trimmed to prevent transpiration. The cut ends of the excised shoots were treated with carbendazim 50 % WP (2%). The cut end of the shoots was then dipped in different concentrations of growth hormones (Table 2), prepared in talc (powder form), and planted in the root trainers filled with sterile vermiculite. The root trainers were maintained in the mist chamber. During day time, an intermittent mist of 30 seconds every 30 minutes was used to maintain the relative humidity between 80 and 95 percent. After 55 days, rooted cuttings were observed for root parameters such as root length (cm), the number of roots, and rooting percentage (%).

Table 1. Weather parameters under different growing conditions during the experimental period

Weather parameter	Inside mist-chamber	Open condition
Temperature (°C)	30±1°C to 33±1°C	27±1°C to 30±1°C
Relative humidity (%)	85% to 95%	65% to 80%
Soil moisture (%)	24.3	12.4

Table 2. Different growth hormone treatment combinations used in the study

Treatments	IBA (mg/L)	NAA (mg/L)
T1	----	----
T2	3000	----
T3	4000	----
T4	----	2000
T5	----	4000
T6	1000	1000
T7	2000	2000
T8	3000	3000

IBA: Indole butyric acid; NAA: Naphthalene acetic acid

Influence of shoot size on rooting of juvenile epicormics shoots: The juvenile epicormic shoots produced from the branch cuttings were collected at three to four pair leaf-stage and categorized into three diameter classes *viz.,* 2.50-4.00 mm, 4.00-5.50 mm, and 5.50-7.00 mm. Cuttings after fungicide treatment were treated with IBA (6000 mg/L), prepared in talc (powder form) and planted in root trainers filled with the sterile vermiculite, and maintained under mist conditions for rooting. The experiment was laid out as CRD with three replications with five shoot cuttings forming one replication. After 45 days of planting, rooted cuttings were prickled out and observed for rooting.

Data analysis: Data collected from the above experiments were analysed using R software version 4.0.4. The effect of growing conditions on epicormic shoot production and physiology under two growing conditions was compared using a t-test. The effects of growth hormone on epicormic shoot production and rooting were studied using DMRT postdoc analysis. Spearman correlation was performed to know the association between the size of the shoot and rooting.

RESULTS AND DISCUSSION

Production of epicormic shoots: The epicormic shoots are the juvenile shoots produced due to dormant budburst. The shoot production was varied under growing conditions and hormonal application.

Effect of growing condition on growth, production, and physiology of epicormic shoots: The prevailing environmental conditions such as light availability, temperature, and humidity are always considered as the primary factor for the epicormic bud dormancy release, physiological activity, and elongation of shoots (Gordon et al 2006). The temperature and relative humidity significantly influence shoot production, shoot biometric and shoot physiological traits. Budburst and other shoot growth parameters except shoot diameter were higher in the mist chamber condition than in the open shed (Table 3). The shoot initiation was observed on the same date between the conditions as an immediate response of branch cuttings to the stress level. An average of 18 shoots with a mean length of 12.17 cm was recorded under mist conditions, whereas only ten shoots of nearly half-length (6.63 cm) were observed under open shed conditions (Plate 01b). Growing conditions were found to have a significant influence on the leaf area too. The leaf area was 36.87 cm^2 under the moist condition, whereas in the open condition was only 16.28 cm^2. The variation in leaf length, width, and expansion under favourable conditions have resulted in this difference. The growing condition significantly influenced relative water content and the photosynthetic rate. The photosynthetic rate was also higher in the mist chamber (4.11 $\mu mol\ CO_2\ m^{-2}\ s^{-1}$) than the open condition (3.63 $\mu mol\ CO_2\ m^{-2}\ s^{-1}$). However, the growing condition did not significantly affect other physiological parameters like stomatal conductance, transpiration rate, and total chlorophyll.

The temperature, natural light has positively impacted epicormic shoot production (Akram and Aftab 2009). Greenhouse condition has been shown to improve the shoot production in teak (Palanisamy and Subramanian 2001, Badilla et al 2017); *Casuarina junghuhniana* (Palanisamy et al 2020); *Pterocarpus indicus* (Pinon et al 2021) and other temperate and tropical tree species (Brondani et al 2009, Wendling et al 2013). Light, humidity, and hormone dynamics are significant influencers for shoot production in plants. The enforced production of shoots on a live detached branch under a mist chamber with higher humidity and temperature is an excellent alternative for coppicing, which can also be used to develop a mini-clonal-hedge garden.

Growth hormone-induced epicormic shoots production: The production of epicormic shoots is mainly dependent on the number of dormant buds present in the trunk or the branch. Hormonal activity plays a significant role in juvenile epicormic shoot production from these dormant buds. The cytokinins and auxin interaction have a significant role in the budburst. When higher cytokinin is present than the auxin, it helps sprout dormant buds and promotes the growth of buds (Tworkoski et al 2006, Pallardy 2008). The exogenous application of auxin has a significant influence on shoot induction (Table 4). The combination of auxins, *viz.,* IBA and NAA, slowed down the shoot emergence and production of epicormic shoots. The first shoot initiation was observed in untreated branch cuttings after 7 to 8 days of planting, followed by IBA treated branch cuttings and then IBA+NAA. The production of live buds after dormancy release was influenced by auxin treatment. Auxin treatment was found to delay and reduce the number of live buds. The untreated branch cuttings have produced a maximum number of buds (average 20.27/ branch cutting) followed by IBA treatment (Plate 01a). In contrast, NAA had a negative impact either alone or in combination with IBA. The least live buds were observed in NAA 2000 mg/L (average 11.87/cutting) and NAA 4000 mg/L (12/ branch cutting). The NAA was found to be inhibiting auxin, which reduces the production of shoots (Okao et al 2016).

The harvestable shoot development after bud bursting was on par among the treatments except for NAA treatments. The differences between the live buds produced and harvestable shoots within the same treatment. The maximum harvestable shoots were produced in Control (11.73/branch cutting), followed by IBA treatments, a Combination of IBA and NAA, and finally, NAA alone. This difference in the production of live bud to the final harvestable shoot within the same treatment is also a result of competition among the individual shoots in the epicormic complexes (a group of buds formed at a single position) from the period of bud production to final harvest period. Each complex will produce more than one bud, during the process of development and elongation, limited potential shoots will retain causing the death of weak shoots within the complex (Colin et al 2010). The nutrient uptake by the sprouts in an epicormic complex impacts the growth and development of potential shoots. The tiny buds are likely weaker than the prominent ones; hence, they are suppressed in growth and may die (Cochard et al 2005). The average shoot diameter among the treatments ranged from 5.14 mm (IBA + NAA 2000 mg/L) to 5.97 mm (control). The highest shoot length was recorded in the control (11.29 cm), and the least was found in IBA+NAA 1000 mg/L (5.70 cm). The variation in shoot length is attributed to early bud production, emergence, and elongation of epicormic shoots. The average number of leaves produced was 6 to 9 per shoot. A similar reduction in shoot production after treating the cutting with sucrose and auxin was observed in *I. paraguariensis.* The potential of epicormic shoot production on the trees is influenced by the factors such as light availability, stress, physiology, hormone dynamics, and genetics of species (Bowersox and Ward 1968, Burrows et al 2008). The stress or damage in the tree trunk associated with hormonal changes is the most critical factor influencing epicormic shoot production. Stress-initiated and hormonal signalling plays a crucial role in producing epicormic shoots. The bud dynamics controlled eco-dormancy (Meier et al 2012) and endo-dormancy (Burrows et al 2008) are well explained in many tree species.

Table 3. Effect of growing condition on production, growth, and physiology of epicormic shoots

Parameters	Mist chamber	Open condition	T-value
Number of shoots produced	18.83	10.67	9.50 *
Shoot length (cm)	12.17	6.63	3.84 *
Shoot diameter (mm)	5.67	4.85	1.78
Leaf area (cm^2)	36.87	16.28	4.09 *
Length (cm)	21.65	11.98	4.83 *
Width (cm)	9.22	6.06	3.84 *
Relative water content (%)	69.63	53.22	3.75 *
Photosynthetic rate (μmol CO_2 m^{-2} s^{-1})	4.11	3.63	5.53*
CATD (°C)	-2.33	-0.55	1.90
Stomatal conductance (μmol H_2O m^{-2} s^{-1})	0.048	0.062	0.95
Transpiration rate (μmol H_2O m^{-2} s^{-1})	0.95	0.98	0.12
Total Chlorophyll (SPAD units)	37.47	39.73	1.15

*Significant at 5 %

Table 4. Exogenous growth hormone influence on epicormic shoot production

Treatment	First shoot (DAP)	Live bud (<1cm)	Sprout (>1cm)	Harvestable shoot (>5cm)	Shoot Diameter (mm)	Shoot Length (cm)	Number of leaves
T1	7.07 ± 0.90 ^{c}	20.27 ± 2.42 ^{a}	16.07 ± 2.20 ^{a}	11.73 ± 0.90 ^{a}	5.97 ± 0.30 ^{a}	11.29 ± 1.02^{a}	9.27 ± 0.70 ^{a}
T2	9.80 ± 1.93 ^{bc}	17.07 ± 0.61^{abc}	13.07 ± 0.58 ^{abc}	9.40 ± 0.87 ^{ab}	5.57 ± 0.22^{abc}	8.65 ± 1.40 ^{b}	8.27 ± 0.31^{abc}
T3	7.33 ± 0.23 ^{c}	19.33 ± 4.03 ^{ab}	14.67 ± 1.80 ^{ab}	11.40 ± 0.20 ^{a}	5.63 ± 0.20 ^{ab}	8.66 ± 1.24 ^{b}	6.80 ± 0.40 ^{bc}
T4	11.93 ± 1.22 ^{ab}	11.87 ± 1.86 ^{c}	8.53 ± 1.60 ^{d}	5.20 ± 0.53 ^{c}	5.17 ± 0.33 ^{bc}	6.84 ± 0.33 ^{bc}	6.73 ± 0.83 ^{c}
T5	12.53 ± 1.90 ^{ab}	12.33 ± 2.23^{c}	9.47 ± 1.86 ^{cd}	5.93 ± 0.83 ^{bc}	5.33 ± 0.12 ^{bc}	8.71 ± 0.23 ^{b}	9.00 ± 0.53 ^{a}
T6	12.53 ± 0.42 ^{ab}	15.07 ± 1.42^{abc}	11.67 ± 0.61 ^{bcd}	8.33 ± 0.58 ^{abc}	5.27 ± 0.09^{bc}	5.70 ± 0.94 ^{c}	8.07 ± 0.64^{abc}
T7	11.93 ± 0.58 ^{ab}	14.33 ± 1.72^{bc}	11.00 ± 0.87 ^{bcd}	8.33 ± 0.81 ^{abc}	5.14 ± 0.28 c	7.03 ± 0.24 ^{bc}	7.87 ± 2.08^{abc}
T8	13.67 ± 1.10 ^{a}	16.73 ± 2.20^{abc}	12.40 ± 1.80 ^{abcd}	10.20 ± 0.72 ^{a}	5.46 ± 0.10^{bc}	7.07 ± 0.98 ^{bc}	8.80 ± 0.53 ^{ab}
MSE	2.668	10.481	6.191	5.242	0.074	1.793	1.472
P	0.000*	0.048 *	0.027 *	0.166	0.003 *	0.000 *	0.931

Significant at 5%, DAP: Days after planting

Large and potential buds are expected to sprout early in favorable environmental conditions, whereas smaller buds will remain dormant and act in the later phase. Owing to this nature of bud dynamics, branch cuttings in the present study continuously produced buds even after two harvests of the epicormic shoot (first harvest on the 40th day after planting, second harvest, and third harvests in 30 days intervals). However, the quality of shoots (diameter and intermodal length) and rooting ability deteriorated, and it was not economically feasible to maintain the branch stick cuttings after the third harvest. Progressively, the stored food material in cutting is reduced, epicormic shoot production is reduced, and eventually, the cutting dies. Such observations were made in species like *I. paraguariensis* (Wendling et al 2013) and *A. angustifolia* (Wendling et al 2009). The potential of epicormic shoot production on the trees is influenced by the factors such as light availability, stress, physiology, hormone dynamics, and genetics of species (Bowersox and Ward 1968, Burrows et al 2008). The stress or damage in the tree trunk associated with hormonal changes is the most critical factor influencing epicormic shoot production. Stress-initiated and hormonal signalling plays a crucial role in producing epicormic shoots. The bud dynamics controlled eco-dormancy (Meier et al 2012) and endo-dormancy (Burrows et al 2008) are well explained in many tree species.

Rooting of epicormic shoots: The clonal technology for mass production has significantly impacted the quality of the cuttings and the quantity of hormones used for rooting. The growth hormone application during the rooting will help enhance the rooting potential as an act of metabolic changes. Auxins also help mobilise the carbohydrates to the rooting zone (Husen and Pal 2007). The size of cuttings affects the rooting potential because the food material stored is directly related to the size of cuttings. The rooting potential or ability is directly influenced by the size of cuttings used in the propagation methods.

Effect of growth hormones in rooting of epicormics shoots: Auxins are widely recognised for fostering adventitious roots from vegetative propagules. Both exogenous and endogenous auxins affect the rooting potential and the number of roots produced in cuttings. The effect of exogenous growth hormone application on rooting has shown significant variation between the auxins IBA and NAA. NAA to inhibited the rooting of teak cuttings (Table 5). The highest rooting percentage was recorded in IBA 4000 mg/L (49.19%), followed by IBA 3000 mg/L (41.71%) and control (35.98%) (Plate 01d). Packialakshmi and Sudhagar (2020) observed similar results in teak shoots; IBA was found to increase the rooting potential compared to IAA and NAA. IBA at its highest concentration (6000 mg/L) was better compared to the lower concentrations. Rooting parameters such as root length, diameter, and rooting percentage

Table 5. Effect of exogenous growth hormones on rooting of juvenile epicormic shoots

Treatments	Rooting percentage (%)*	Callusing percentage (%)*	Root length (cm)	Number of roots
T1	35.98 (36.85) ^{c}	17.27 (24.48) ^{f}	9.00±2.05 ^{a}	2.17±0.76 ^{a}
T2	41.71 (40.23) ^{b}	27.98 (31.93) ^{e}	8.78±0.38 ^{a}	3.17±1.15 ^{a}
T3	49.19 (44.53) ^{a}	36.44 (37.11) ^{d}	8.08± 1.47 ^{ab}	3.06± 0.59 ^{a}
T4	5.61 (13.64) ^{e}	5.08 (12.86) ^{g}	1.33± 2.31 ^{c}	1.00± 0.58 ^{b}
T5	14.01 (21.97) ^{d}	5.78 (13.86) ^{g}	6.50± 2.00 ^{ab}	1.00± 0.58 ^{b}
T6	--	50.92 (45.52) ^{b}	--	--
T7	14.15 (22.08) ^{d}	42.87 (40.89) ^{c}	5.50±0.50 ^{b}	1.20± 0.00 ^{b}
T8	13.73 (21.03) ^{d}	55.26 (47.75) ^{a}	7.00±0.50 ^{ab}	1.80± 0.00 ^{b}
MSE	2.06	5.89	2.16	0.36
P (0.001)	0.00	0.00	0.00	0.00

* Values in parenthesis is square rooted transformed values

Table 6. Influence of shoot size on rooting of juvenile epicormics shoots

Shoot diameter class	Mean shoot diameter (mm)	Shoot length (cm)	Number of leaves	Rooting percentage (%)*	Root length (cm)	Number of roots
2.50-4.00 mm	3.43±0.41 ^{c}	8.03±0.60 ^{b}	5.39±0.98 ^{a}	50 (45.03) ^{b}	7.48±1.61 ^{b}	1.33±0.29 ^{b}
4.01-5.50 mm	4.79±0.34 ^{b}	12.27±2.66 ^{ab}	5.33±2.01 ^{a}	65 (53.87) ^{b}	10.94±0.74 ^{a}	2.06±1.11 ^{b}
5.51-7.00 mm	6.72±0.57 ^{a}	12.61±2.50 ^{a}	6.03±1.78 ^{a}	85 (67.40) ^{a}	11.83±1.09 ^{a}	3.83±0.45 ^{a}
MSE	0.205	4.564	2.819	37.401	1.445	0.503
P (0.05)	0.0003	0.0699	0.8569	0.0118	0.0098	0.0126

* Values in parenthesis is square rooted transformed values

increased with increasing IBA concentration compared to other auxins. These effect of exogenous application of IBA has been reported to increase the rooting in teak (Husen and Pal et al 2007, Husen 2013, Guleria and Vashisht 2014, Packialakshmi and Sudhagar 2019) and other tree species (Kala et al 2018, Pinon et al 2021, Olaniyi et al 2021). However, a very high concentration of IBA may result in mortality of shoots followed by necrosis. However, the concentrations tried in the experiment were not to these toxic levels.

NAA inhibited rooting and promoted callus formation at the cut ends in teak shoots. The cutting treated with NAA (T4- 2000 mg/L, T5- 4000 mg/L) showed only 5.61% and 14.01% rooting. A similar inhibitory effect of NAA has been reported earlier (Gordon et al 2006, Kesari et al 2009, Packialakshmi and Sudhagar 2019). The highest callusing was observed in the combination of IBA and NAA 3000 mg/L (55.26 %), followed by IBA + NAA 1000 mg/L (50.92 %), IBA + NAA 2000 mg/L (42.87%), and IBA 4000 mg/L (36.44 %). The combination of IBA and NAA encouraged maximum callusing at a given period. The cumulative response percentage for rooting callus formation was highest in IBA 4000 mg/L (85.63%) followed by IBA 3000 mg/L, IBA + NAA 3000 mg/L, IBA + NAA 2000 mg/L , control (53.25%) (Fig. 1). The IBA+NAA @3000 mg/L recorded high percentile rooting as synergistic action. Similar inhibitory effects of NAA were reported in *Pongamia pinnata* (Kesari et al 2009) and *Ficus schlechteri* (Henselova 2002). The highest root length was observed in control and IBA treatments. The least root length was in NAA 2000 mg/L. The maximum number of roots were in IBA treatments, and the least was in NAA treatments.

Influence of Shoot size on rooting of epicormics shoots: The size of epicormic cuttings greatly influenced the rooting percentage, root length, and the number of roots. The epicormic shoots under the different size classes had significant variation in mean shoot length as the selection was made according to size class (Table 6). All root parameters were lower in smaller cuttings. The rooting percentage was highest (67.40%) in size class - 5.50 to 7.00 mm and least (45.03%) in size class 2.50 to 4.00 mm. Root biometric parameters such as root length and the number of roots were highest in 5.50-7.00 mm size cuttings (11.84 cm and 3.83 respectively) with an average shoot length of 12.61 cm. 4.01 to 5.50 mm size shoots with 10.94 cm root length, 2.06 cm number of roots and 12.27 cm shoot length (Plate 01c). The lesser shoot diameter was observed with the least root length and other root and shoot parameters.

The results of the present study are also supported by other research findings on different tree species (Kathiravan 2009, OuYang et al 2015, Okao et al 2016, Kala et al 2018, Olaniyi et al 2021). Cutting diameters has shown a significant effect on the root regeneration and shoot formation in teak (Guleria and Vashisht 2014). Packialakshmi and Sudhagar (2019) reported maximum rooting in 3 to 5 mm diameter, 5 cm length teak cuttings. In *Picralima nitida,* cuttings of length >8 cm had higher rooting properties than 6 cm and lower (Olaniyi et al 2021). Kala et al (2018) recommended using 25mm diameter semi-hardwood stem cutting with 15 cm length for propagation in *Pongamia pinnata* compared to the smaller sizes. The size class effects are attributed to the carbohydrate stored in cuttings and the number of leaves retained in cuttings. Leaves present in the cuttings help in carbon assimilation and hence affect the development of root and shoot structures.

Correlation analysis was used to study the relationship between the size of the epicormic shoot and the rooting parameter (Fig. 2). The rooting percentage showed a significantly positive correlation with shoot diameter (r=0.89) and was not affected by the number of leaves. The number of

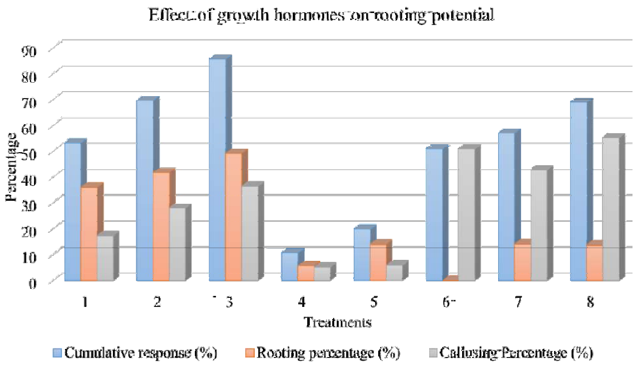

Fig. 1. Effect of exogenous growth hormone on rooting potential

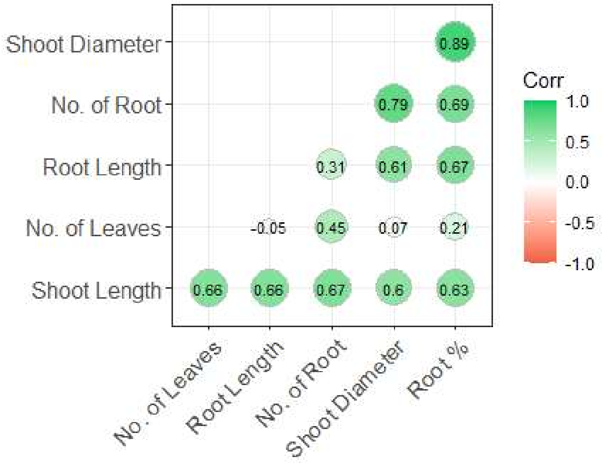

Fig. 2. Relation between the shoot parameters and rooting character

roots positively correlated with shoot diameter and shoot length . The number of leaves had no relation to rooting. A similar relation between the shoot character and rooting potential was reported in earlier studies (Kathiravan 2009, OuYang et al 2015).

The study indicates that the induction of juvenile shoots on branch cutting is more efficient for the vegetative propagation of matured trees. Under mist chamber, the average number of epicormic shoots production was 12 per branch. The untreated and lower concentration of IBA was on par and found to have no effect on epicormic shoot production on branch cuttings, whereas NAA alone and in combination with IBA had negatively influenced the shoot production. The study also supports the use of larger cuttings

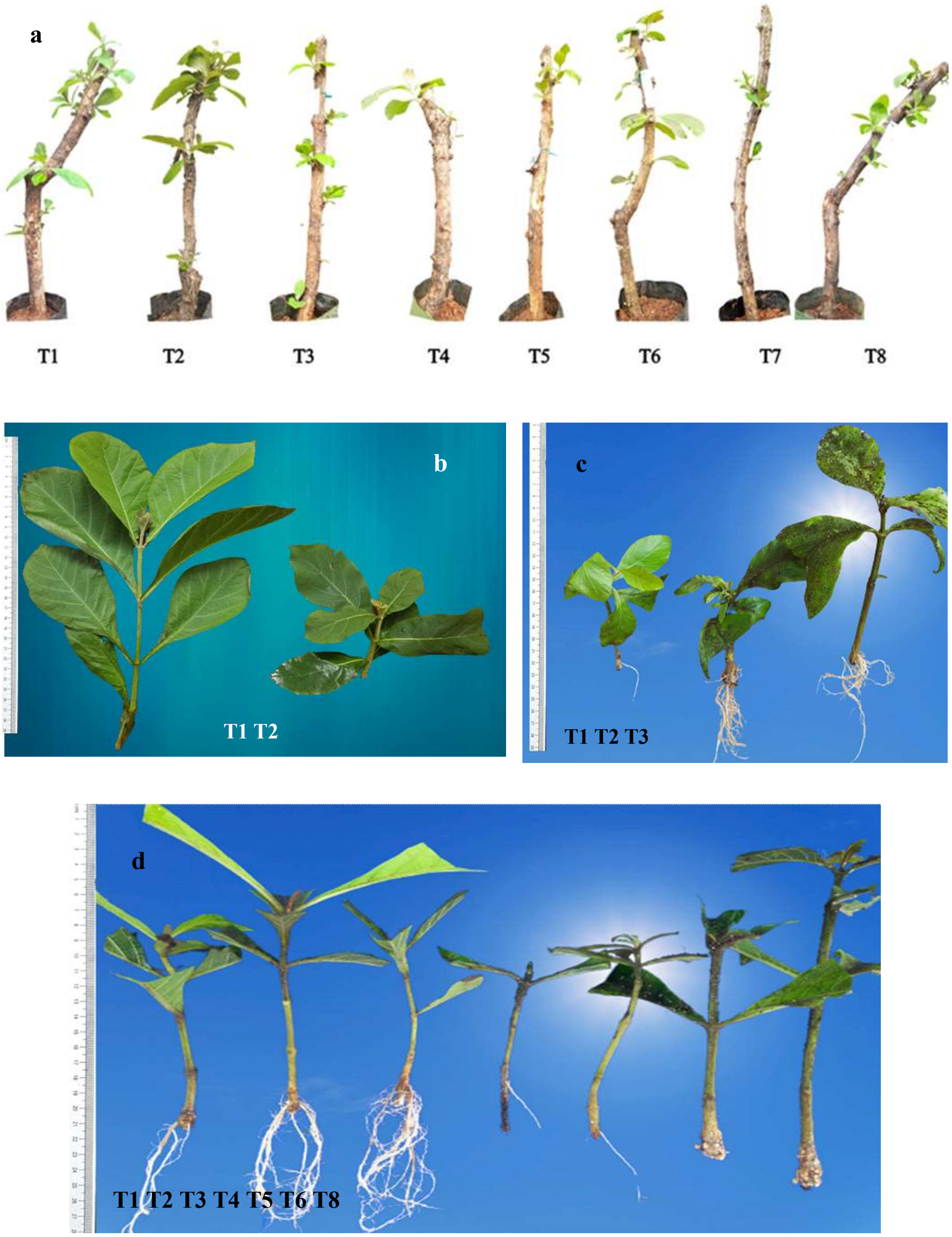

Plate 1. Production and Rooting of epicormic shoots; a. Influence of exogenous growth hormone on shoot production (25th day after planting), b. Effect of growing condition on juvenile shoots- (T1) inside mist chamber and (T2) open shed condition (cuttings taken on 55th days after planting), c. Influence of shoot size on rooting of juvenile Epicormics shoots- T1 (2.50 - 4.00 mm), T2 (4.00 -5.50 mm), and T3 (5.50 - 7.00 mm) (45th day after treatment), d. Effect of exogenous growth hormones on rooting of juvenile epicormic shoots (55th day after treatment)

(>4 mm) together with exogenous application of IBA (@ 3000mg/L and more) for successful rooting of the excised shoots. There is scope for developing specific studies on the shoot production from branch cuttings to determine the best season with compatible hormonal studies, nutrient management for maximising the production, physiology of bud dormancy release, and anatomical and ontogenetic studies.

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