Adaptive variation in adventitious rooting among Tectona grandis clones

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Title Page

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Abstract

This study examined rooting performance of teak (Tectona grandis) micro-cuttings across 10 clones and 3 hormone treatments at 4 concentrations. Root development was categorised into five stages, with hormone application accelerating initiation compared to controls. Statistical analysis showed significant differences among clones and treatments, confirming that rooting ability is strongly genotype-dependent. Descriptive statistics showed variation in rooting rate, root number, length, width, node thickness, and root effect index, with IBA and NAA treatments enhancing root initiation. Grey Relational Analysis (GRA) was applied to multi-trait optimisation, identifying varying IBA treatment concentrations as broadly effective, though clone-specific responses were evident. Time-course regression confirmed progressive improvement in rooting traits ($R^2 > 0.90$), with early-rooting clones (TG1, TG4, TG12) showing steep increases, while slow-rooting clones (TG19 and TG20) remained less responsive. The GRA heatmap further emphasised genotype-dependent variation. It is evident that rooting success in teak requires multi-trait evaluation and clone-specific optimisation of hormone type and concentration, especially for mass production.

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Funding declaration

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Statements and Declarations

Ethics approval and consent to participate

The plant material used in this study comprised tissue-culture derived clonal plants of *Tectona grandis* maintained under controlled conditions at Tissue culture laboratory of the ICFRE-Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore, India. No wild plant material and no samples were collected from protected areas. The plant material was obtained from the institute's in vitro clonal collection and used in accordance with the institutional policies governing research material. As the study did not involve the collection of wild plant specimens, no specific collection permits or licenses were required. This study did not involve human participants or animals, and therefore consent to participate is not required.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Permissions for plant collection

The tissue-culture derived teak clones used in this study were obtained from the Tissue culture laboratory of the ICFRE- Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore, India, with Institutional permission. No additional permits or licenses for plant collection were required for the study.

Authors' contributions

KE was involved in methodology, nursery and laboratory work, AS supported laboratory work, RM supported the field/nursery work, RRW contributed to conceptualisation, methodology, resources, supervision, funding acquisition, writing original draft and editing. All authors read and approved the final manuscript.

Conflicts of interest/Competing interests

Authors declare no conflict of interest.

Significance statement

This work demonstrates that rooting success in teak is strongly genotype-dependent, requiring clone-specific strategies. Application of auxins significantly enhanced root initiation and development across multiple traits. Grey Relational Analysis provided a robust framework for multi-trait optimisation of hormone treatments. The findings offer practical guidance for efficient mass propagation of teak through micro-cuttings.

Data archiving statement

Information related to the clones is archived in the Fischer Herbarium, ICFRE-IFGTB, Coimbatore.

Gene & accession numbers
Not Applicable

Ethics statement
Not Applicable

Patient consent statement
Not Applicable

Permission to reproduce material from other sources
Not Applicable

Statement on AI Use
Artificial intelligence tools - Microsoft Copilot and Grammarly were used to assist in language editing and improve the clarity of the manuscript. The authors confirm that all intellectual content, data interpretation, and conclusions are their own, and the AI tool did not contribute to the generation of scientific results or analysis.

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Abstract

This study examined rooting performance of teak (Tectona grandis) micro-cuttings across 10 clones and 3 hormone treatments at 4 concentrations. Root development was categorised into five stages, with hormone application accelerating initiation compared to controls. Statistical analysis showed significant differences among clones and treatments, confirming that rooting ability is strongly genotype-dependent. Descriptive statistics showed variation in rooting rate, root number, length, width, node thickness, and root effect index, with IBA and NAA treatments enhancing root initiation. Grey Relational Analysis (GRA) was applied to multi-trait optimisation, identifying varying IBA treatment concentrations as broadly effective, though clone-specific responses were evident. Time-course regression confirmed progressive improvement in rooting traits ($R^2 > 0.90$), with early-rooting clones (TG1, TG4, TG12) showing steep increases, while slow-rooting clones (TG19 and TG20) remained less responsive. The GRA heatmap further emphasised genotype-dependent variation. It is evident that rooting success in teak requires multi-trait evaluation and clone-specific optimisation of hormone type and concentration, especially for mass production.

Introduction

Tectona grandis, commonly known as teak, is a tropical hardwood species belonging to the family Lamiaceae. It is indigenous to India, Myanmar, Laos and Thailand (Pandey and Brown, 2000; Tropicos, 2025). Teak is regarded as one of the world's premier hardwood timbers and is highly sought for its remarkable physical properties, such as shape retention, high tensile strength, durability, and natural resistance to termite and fungal attack (Thulasidas and Bailleres, 2017). Globally, teak is considered one of the most important tropical hardwood resources and remains a priority species for large-scale cultivation (Kollert *et al*., 2024).

Despite its economic importance, teak production faces significant challenges. Strict conservation rules to maintain natural stocks, a 60-80-year harvest period in traditional teak plantations, and a poor seed germination rate have led to a shortage of teak wood supply (Dhaka *et al*., 2024). As a result, global demand for teak wood continues to far exceed available resources. To bridge this gap, the vegetative propagation method can be opted for. Though teak propagation with semi-hardwood cuttings has been known for decades (Monteuuis, 2000; Palanisamy *et al*., 2001; Ansari *et al*., 2002; Singh *et al*., 2005; Husen, 2011), it has several limitations, and from selected individuals, only a few propagules can be obtained. In contrast, micropropagation through tissue-culture (Yasodha *et al*., 2005; Venkatachalam *et al*., 2024) enables mass multiplication of superior trees, genetic uniformity and large-scale production in short period of time.

The success of any propagation method relies on the planting materials ability to form adventitious root. Adventitious root formation comprises of three phases namely, induction phase where molecular and biochemical changes occur, initiation phase where root primordia formation, small cells with large nuclei and dense cytoplasm occur, expression phase where emergence of root primordia occur (Pacurar *et al*., 2014; Gonin *et al*., 2019). The process of adventitious root formation is a complex process influenced by both external factors like temperature, humidity, light as well as internal factors like phytohormones- auxin, gibberellin, cytokinin, ethylene, abscisic acid, carbohydrate and nitrogen content. Among the internal factors, the phytohormone auxin plays a significant role in adventitious root formation. Studies have shown that during root induction, cuttings base have higher level of endogenous auxin content (Druege *et al*., 2019). Furthermore, many plants exhibit a rooting response when treated with exogenous auxin, indicating that auxin stimulates rooting. The application of exogenous auxin or the presence of endogenous auxin can stimulate adventitious root formation. Since the use of auxin hormone to promote rooting, several synthetic auxins such as indole-3-butyric acid (IBA) and naphthalene acid (NAA) have been found to promote rooting (Overvoorde *et al*., 2010; Reddy *et al*., 2022).

However, vegetative propagation method continues to face significant challenges, particularly due to difficulties in adventitious root formation and variability in rooting ability among certain genotypes of commercially important woody species. This variation in rooting ability is a major constraint for large-scale commercial propagation. Studies on teak

micropropagation have shown that rooting responses can vary widely among clones (Sawitri *et al*., 2020), with some exhibiting poor root induction despite similar treatments, thereby highlighting the genotype-dependent nature of rooting competence in clonal propagation.

The variation in rooting ability among clones highlights the need for clone-specific propagation strategies. In addition to inherent genetic differences, variation in response to auxin type and concentrations further influences rooting success, making uniform protocols less effective across all clones. Previous studies have also demonstrated the suitability of vermiculite as an efficient rooting substrate (Warrier *et al*., 2022), providing a supportive medium for root development. In this context, the present study aimed to determine the optimal hormone and concentration combination for teak clone propagation by integrating multiple rooting traits. This approach aims to reduce variability among clones, improve root quality, and enhance overall propagation efficiency, thereby facilitating synchronized rooting and supporting large-scale clonal multiplication.

Materials and methods

Plant materials/clones

Ten teak clones namely TG1, TG2, TG3, TG4, TG5, TG8, TG12, TG15, TG19 and TG20 from the Tissue Culture laboratory, ICFRE-Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore were selected for the study (Fig. 1). These clones were developed from superior teak trees selected through the genetic improvement program. The experiments were carried out at the nursery of ICFRE-IFGTB, Coimbatore (11.0176° N, 76.9514° E).

Figure 1. Selected *Tectona grandis* genotypes maintained in the laboratory

Experimental design

The experiment was laid out in a factorial arrangement under a completely randomized design (CRD) to analyse the effect of different auxin hormone and its varying concentration on the rooting factors of ten teak clones under ex-vitro condition. This experiment includes three factors: the exogenous hormone type, varying concentration and ten teak clones are shown in Table 1. All the clones were treated with treatment combinations shown in Table 2. Experimental design includes 12 treatment combinations along with a control. Each treatment consisted of three replicates, with 10 shoots per replication. Prior to hormone treatment microshoots were treated with Bavistin treatment to prevent fungal contamination. The auxin hormones were prepared in solution formulation and the basal nodal region was dipped in corresponding concentration for 10 minutes. After treatment microshoots were transferred to hycopots filled with vermiculite and maintained in polytunnel.

Table 1. Experimental factors

Experimental factors		
Clones	**Types of Hormone**	**Concentration (ppm)**
TG1	IAA	250
TG2	IBA	500

TG3	NAA	750
TG4		1000
TG5		
TG8		
TG12		
TG15		
TG19		
TG20		

Table 2. Treatment and its combinations

Treatment number	Treatment combination	Hormone	Concentration
1.	A1B1	IAA(A1)	250(B1)
2.	A1B2	IAA(A1)	500(B2)
3.	A1B3	IAA(A1)	750(B3)
4.	A1B4	IAA(A1)	1000(B4)
5.	A2B1	IBA(A2)	250(B1)
6.	A2B2	IBA(A2)	500(B2)
7.	A2B3	IBA(A2)	750(B3)
8.	A2B4	IBA(A2)	1000(B4)
9.	A3B1	NAA(A3)	250(B1)
10.	A3B2	NAA(A3)	500(B2)
11.	A3B3	NAA(A3)	750(B3)
12.	A3B4	NAA(A3)	1000(B4)
13.	Control(CK)	Water	0

Rooting traits measurement

From the root initiation until primary hardening period i.e. day 60, rooting traits and its development stages were analysed. Several rooting factors including average root number, average root length, average root width, average node width, root effect index and rooting rate were measured for all the 13 treatment combinations. Formulae for these indices are as follows:

$$\text{Average root number} = \text{Total root number}/\text{Number of rooted shoots}$$

$$\text{Average root length} = \text{Total root length}/\text{Total number of roots}$$

$$\text{Average root width} = \text{Total root width} / \text{Total number of roots}$$

$$\text{Average node width} = \text{Total node width} / \text{Number of rooted shoots}$$

$$\text{Root effect index} = (\text{Average root length} \times \text{Number of rooted shoots}) / \text{Total number of shoots}$$

$$\text{Rooting rate} = (\text{Number of shoots rooted} / \text{Total number of shoots}) \times 100\%$$

Statistical analysis

Data was pre-processed using excel and all statistical analyses were performed using SPSS. The effects of treatments on rooting traits were evaluated using analysis of variance (ANOVA) and Range. Descriptive statistics such as mean and standard error were determined for all measured rooting traits. Difference among treatment mean values were tested using Post hoc-Duncan Multiple Range Test (DMRT) at 5% level of significance. Pearson correlation was conducted to study the relationship among the rooting traits. Furthermore, the interrelationship between multiple rooting traits and treatment was assessed using multiple attribute decision making method- Grey Relational Analysis (GRA), where higher grey relational grade indicate superior rooting performance. The resulting GRA scores were visualized using heatmap analysis and time-course growth curve regression for better interpretation of treatment effects. The steps involved in GRA are as follows:

Step 1: Data normalization

Data normalization is the first step in GRA, data are normalized to the values between 0 and 1 by Eqs. (1) and (2) depending on larger-the-better and smaller-the-better characteristic: The larger-the-better approach was applied to the rooting factors such as average root length, average root number (ARN), average root width (ARW), average node width (ANW), root effect index (REI) and rooting rate (S)

$$x_i(k) = \frac{x_i(k) - \min x_i(k)}{max\ x_i(k) - min x_i(k)} \quad (1)$$

The smaller-the-better approach was applied to days taken for root initiation

$$x_i(k) = \frac{max\ x_i(k) - x_i(k)}{max\ x_i(k) - min x_i(k)} \quad (2)$$

where, max $x_i(k)$ = maximum value of $x_i(k)$ and min $x_i(k)$ = minimum value of $x_i(k)$

Step 2: Calculation of deviation sequence

The deviation sequence $\Delta O_i(k)$ represents the absolute difference between the highest normalised value for each response, and is given by equation 3

$$\Delta O_i(k) = | x_0(k) - x_i(k)| \quad (3)$$

where, $x_0(k)$ = Largest normalised value of output and

and $x_i(k)$ = Normalized value of output variable in i^{th} experiment

Step 3: Determination of grey relational coefficient

For each variable, Grey relational coefficient value (GRC) is derived from the response $\Delta O_i(k)$ value as per equation 4. The GRC determines the relationship between the desired and actual experimental results using a distinguishing coefficient ζ,

$$\gamma_i(k) = \frac{\Delta_{min} + \zeta \Delta_{max}}{\Delta O_i(k) + \zeta \Delta_{max}} \quad (4)$$

where, Δ_{min} = the series of deviations with the smallest value,

Δ_{max} = the series of deviations with the highest value,

ζ is the GRC, which was considered as 0.5 in the study.

Step 4: Calculation of grey relational grade

The grey relational grade shows the overall performance of each treatment, which can be calculated using Eq. (5)

$$\Gamma_i = \frac{1}{n} \sum_{k=1}^{n} \gamma_i(k) \quad (5)$$

where Γ_i is the grey relational grade for the i^{th} treatment, $\gamma_i(k)$ is the GRC of the k^{th} response, and n is the total number of response variables. In this study, equal importance was assigned to all response variables, therefore the GRG was calculated as the arithmetic mean of the GRC values. A higher value of Γ_i indicates better overall performance of the corresponding treatment.

Results

Rooting stages

Root development in teak micro-cuttings was categorized into five distinct stages. **Stage I (0–5 days)** represented the *early emergence phase*, with no visible roots but initial

physiological activity at the nodal region. **Stage II (5–15 days)** marked the *emergence phase* and considered as root initiation period, during which milky white root primordia (≤1 cm) began to protrude. **Stage III (15–30 days)** corresponded to the *early phase of adventitious root formation*, characterized by the enlargement of the hormone-treated nodal region. **Stage IV (30–45 days)** was the *elongation phase*, in which the number and length of adventitious roots increased significantly. Finally, **Stage V (45–60 days)** represented the *formation of massive adventitious roots*, where a well-developed root system with a distinct brown coloration was observed. In comparison, control treatments exhibited delayed root emergence and produced fewer adventitious roots.

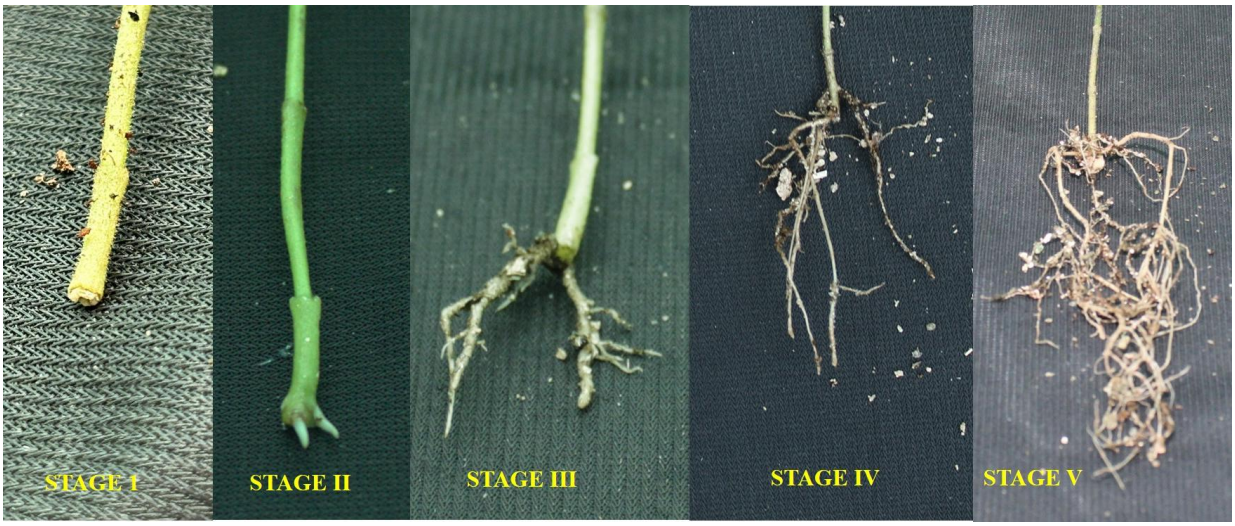


Figure 2. Adventitious rooting process of the teak genotypes categorised into five stages.

Influence of treatment

Analysis of variance results (ANOVA) (Table 3) revealed clones differed significantly for all the rooting traits measured, including average root number, average root length, average root width, average node width, rooting rate and root effect index. This highlights the role of genotypic variability in determining the rooting capacity of teak. Hormone type significantly influenced ARN, S and REI, while concentration level had a significant effect only on S. Significant interaction effects were found between hormone and genotype, as well as concentration and genotype on ARN and S. But there was no significant interaction effect on ARL, ARW, ANW and REI. The survival was effected by all treatments and their interaction, showing the influence of genotype, hormone and concentration on this survival trait.

Table 3. Analysis of variance for treatment effect on clones rooting parameters

Source	ARN		ARL		ARW		ANW		S		REI	
	F	P	F	P	F	P	F	P	F	P	F	P
A	9.670**	0.000	8.836**	0.000	14.661**	0.000	33.069**	0.000	139146.567**	0.000	16.086**	0.000
B	15.898**	0.000	1.338 ns	0.263	0.713 ns	0.491	2.677 ns	0.070	28141.750**	0.000	3.497*	0.031
C	1.837ns	0.140	1.149 ns	0.329	0.227 ns	0.877	0.082 ns	0.970	10219.083**	0.000	1.469 ns	0.222
AxB	6.132**	0.000	0.714 ns	0.797	0.551 ns	0.932	1.095 ns	0.355	6701.380**	0.000	1.216 ns	0.244
AxC	2.022**	0.002	0.448 ns	0.993	0.571 ns	0.960	1.388 ns	0.097	4900.318**	0.000	0.717 ns	0.851
BxC	1.911 ns	0.078	0.526 ns	0.789	0.977 ns	0.441	0.706 ns	0.645	4343.083**	0.000	0.623 ns	0.712
AxBxC	0.827 ns	0.803	0.27 ns	1.000	0.378 ns	1.000	0.868 ns	0.734	2746.170**	0.000	0.356 ns	1.000

A: Clone; B: Hormone; and C: Concentration. The "*" shows significant differences between each treatment while $p < 0.05$, the "**" shows very significant differences between each treatment while $p < 0.01$, and the "ns" shows not significant

Figure 3 illustrates the results of the range analysis for rooting traits in response to different hormone types and concentrations. When S was considered as the primary indicator, the corresponding *R*-values were 0.105 for hormone type and 0.099 for concentration, indicating that hormone type exerted a slightly greater effect on S. For ARL, the *R*-values were 0.533 for hormone type and 0.682 for concentration, suggesting that concentration had a stronger effect on root elongation than hormone type. When ARN, was used as the primary indicator, the *R*-values were 0.825 for hormone type and 0.409 for concentration, indicating that hormone type had stronger effect on root proliferation.

Similarly, for ARW, the *R*-values were 0.051 for hormone type and 0.042 for concentration, again showing that hormone type had stronger effect on root thickness.

For REI, the R-values were 0.735 for hormone type and 0.711 for concentration, indicating a stronger influence of hormone type on REI. Similarly, for ANW, the R- value were 0.138 for hormone type and 0.032 for concentration, showing that hormone type had greater influence than concentration. Overall, the range analysis indicates that hormone type had a stronger effect on most rooting parameters—including S, ARN, REI, ANW, and ARW—whereas , concentration had a greater impact on ARL.

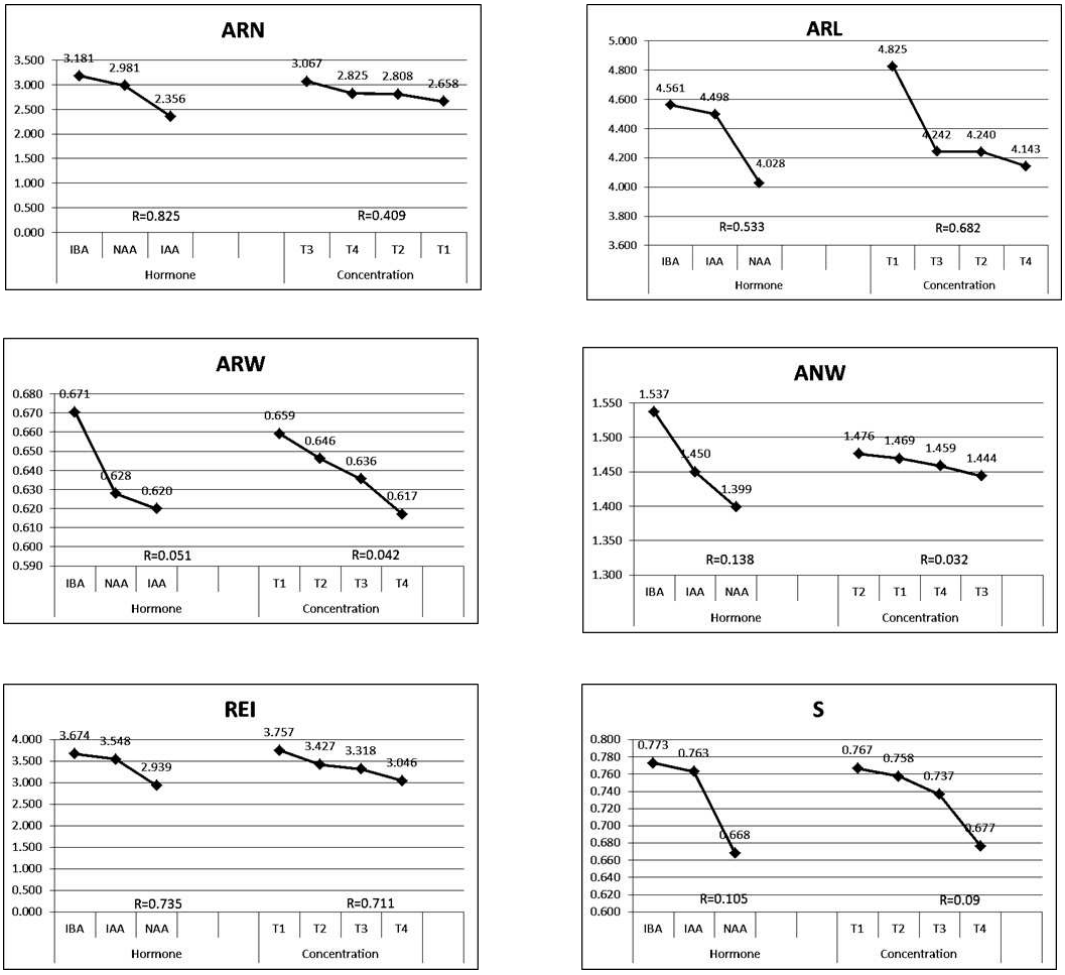


Figure 3. Influence of hormone treatment on rooting factors. T1, T2, T3 and T4 corresponds to 0, 250, 500 and 1000 ppm concentration respectively.

Effect of hormone type and varying concentration on genotypes and its rooting traits

Descriptive statistics (Table S1) provided an overview of rooting performance across different clones and treatments, indicating differences in overall rooting ability. Post hoc analysis (Fig. 4) further confirmed that these differences were statistically significant. These results indicate that both clone type and hormone treatment significantly influenced rooting performance.

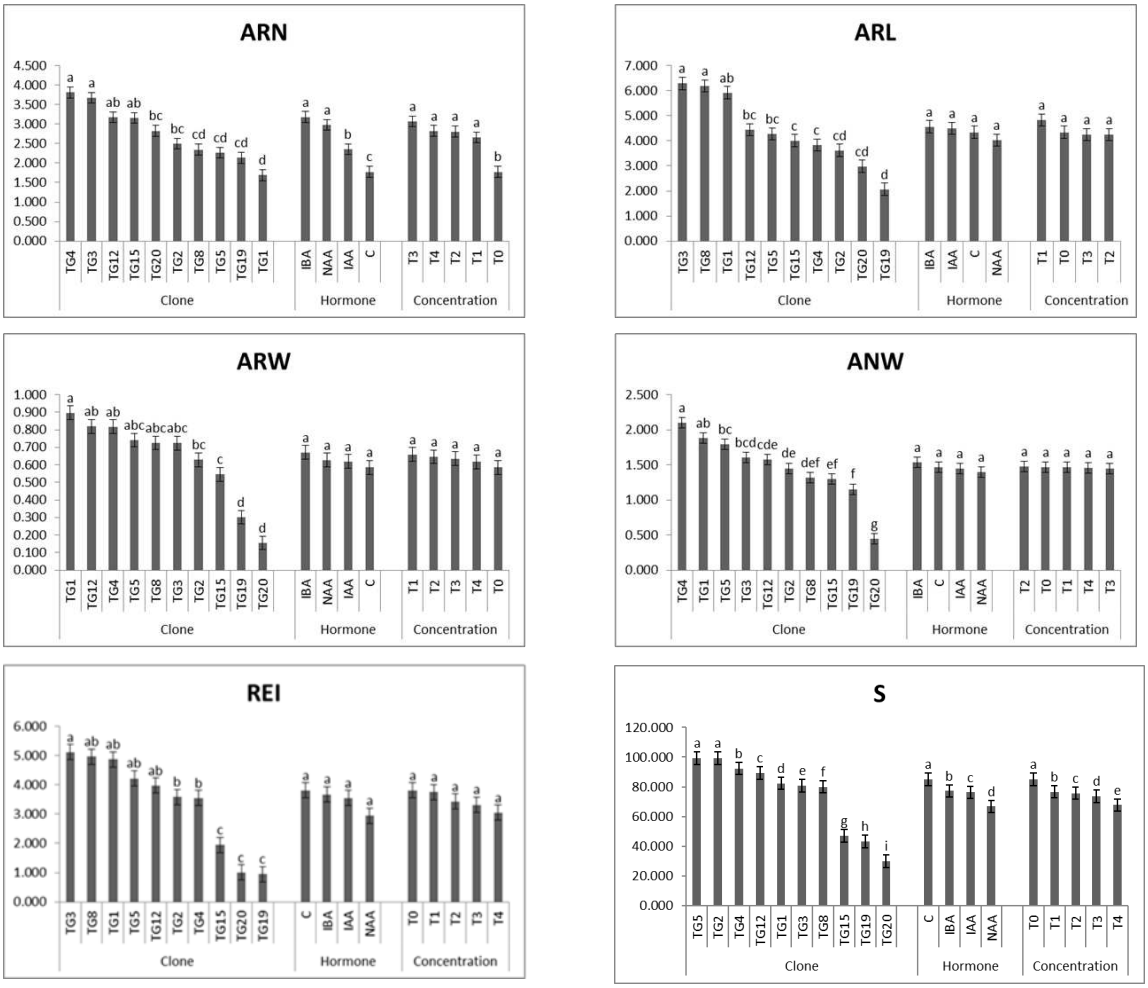


Figure 4. Duncan test showed clone performance and treatment effect on the rooting parameters. Different lowercase letters denote subset. T0, T1, T2, T3 and T4 corresponds to 0, 250, 500 and 1000 ppm concentration respectively.

Effect of hormone treatment on rooting rate

Rooting rate varied among clones and treatments. Mean values (Table S1) showed that several clones including TG1, TG2, TG3, TG4, TG5, TG8 and TG12 achieved 100% rooting rate. Clone TG15 also showed a high rooting rate of 90%. In contrast, clones TG19 and TG20 attained their maximum rooting percentage, ranging 50-80%. The Duncan test (Fig. 4) separated clones into statistically distinct groups, with several exhibiting high rooting ability (>80%) and a few showing comparatively lower rooting capacity (<80%). Clones **TG5** and **TG2** recorded the highest rooting rate, whereas **TG20** displayed the lowest. The **control** treatment achieved the highest average rooting rate, followed by **IBA**. Similarly, the **0ppm,** followed by **250 ppm**

concentrations showed higher average rooting rates. Although the control exhibited superior rooting percentage, hormone-treated clones showed earlier root initiation compared to the untreated group.

Effect of treatment on average root number

According to mean values shown in Table S1, ARN was observed among clones and hormone treatment. Clones TG3 and TG4 showed the highest ARN ranging from 6-7. Clones TG1, TG2, TG5, TG8, TG12, TG15, TG19 and TG20 showed ARN ranging from 3-5. The post-hoc Duncan test (Fig. 4) further revealed that clones TG4, TG3, TG12, and TG15 were statistically similar and produced the highest average number of roots. The maximum ARN was observed at 750 ppm, followed by 1000 ppm, which did not differ significantly from 500 ppm and 250 ppm. Among hormone treatments, IBA and NAA were statistically similar and yielded the highest number of roots across all clones, whereas the control group produced the fewest.

Effect of treatment on average root length

Mean values (Table S1) showed clones TG1, TG3 and TG8 produced the longest roots with ARL exceeding 7cm, while clones TG2, TG4, TG5, TG12, TG15, TG20 exhibited intermediate values ranging from 5-6 cm. The shortest ARL was recorded in clone TG19 below 3cm. Post-hoc comparisons (Fig. 4) further showed that clones TG3, TG8, and TG1 were statistically similar and exhibited the highest ARL whereas TG19, TG20 and TG2 showed the lowest ARL values. All the treatment showed statistically similar effects on ARL.

Effect of treatment on average root width

Mean values (Table S1) showed the maximum ARW was recorded in TG12, followed closely by clones TG1, TG4 and TG5 all exhibiting values around 1mm. Clones TG2, TG3 and TG8 showed values ranging between 0.8-0.9 mm. By contrast, clones TG19 and TG20 clones produced relatively thinner ARW with values ranging from 0.4-0.5mm. Further, post-hoc test (Fig. 4) showed clone TG1 produced the greatest ARW, followed by TG12, TG4, TG5, TG8, and TG3, which were not significantly different from each other. However, clones TG19 and TG20 showed the least mean values. All treatment showed statistically similar effects on ARW.

Effect of treatment on average node width

Mean values (Table S1) showed that the highest node thickness was recorded in TG4, followed closely by TG1, TG5 and TG15 with about 2 mm ANW. Followed by, clones TG2 and

TG3 also exhibited high ANW ranging around 1.8-1.9 mm. TG8 and TG19 showed its maximum ANW ranging around 1.7 mm. TG20 clone showed its maximum ANW less than 1mm and was the lowest among the clones. Further, post-hoc test (Fig. 4) showed that the clones TG4 and TG1 recorded the highest ANW and were statistically similar. However, clone TG20 showed the least mean value. All treatment showed statistically similar effects on ANW.

Effect of treatment on root effect index

Mean values (Table S1) showed that the highest REI value was recorded in clone TG1, followed closely by clone TG3, both showing values around 7. Clones TG2, TG4, TG5, TG8, TG12, TG15 also exhibited high REI ranging around 4-6. In contrast, clones TG19 and TG20 were comparatively low REI, below 3. Further post-hoc test (Fig. 4) showed clone TG3 achieved the highest REI, followed closely by TG8, TG1, TG5, and TG12, which did not differ significantly. However, clones TG15, TG19 and TG20 showed the least mean values. All treatment showed statistically similar effects REI.

Although mean values for ARL, ARW, ANW and REI were higher in the hormone-treated samples compared to the control, Duncan's test grouped these treatments within the same homogeneous class. In contrast, IBA and NAA application significantly increased ARN, showing the effectiveness of auxin treatment in promoting root initiation. The differential response among traits suggests that all rooting parameters do not respond uniformly to hormone treatments.

Correlation

The correlation is displayed in Table 5, conducted to evaluate the association among the rooting factors. ARN showed moderate but significant correlation with ARL ($r=0.414^{**}$), ARW ($r=0.331^{**}$) and ANW ($r=0.349^{**}$), also showed weak but significant correlation with REI($r=0.292^{**}$), suggesting that clones forming more roots also tend to develop longer and thicker roots. ARL showed significant strong correlation with ARW($r=0.665^{**}$), ANW($r=0.589^{**}$) and REI ($r=0.917^{**}$). ARW showed significant strong correlation with ANW($r=0.818^{**}$), S ($r=0.443^{**}$) and REI ($r=0.728^{**}$). ANW showed significant strong correlation with S ($r=0.536^{**}$) and REI ($r=0.675^{**}$). In contrast, rooting rate showed negligible correlation with ARN (r=0.003), also showed weak but significant correlation with ARL ($r=0.202^{**}$) and significant moderate correlation with REI ($r=0.478^{**}$). The variation in correlation strength among rooting traits shows the complex nature of rooting response and indicates that rooting

performance cannot be described by a single parameter, therefore multiple rooting traits should be considered during hormone optimization.

Table 5. Correlation of rooting parameters

	ARN	ARL	ARW	ANW	S	REI
ARN	1					
ARL	.414**	1				
ARW	.331**	.665**	1			
ANW	.349**	.589**	.818**	1		
S	.003 ns	.202**	.443**	.536**	1	
REI	.292**	.917**	.728**	.675**	.478**	1

"**" shows correlation is significant at the 0.01 level (2-tailed), and "ns" shows not significant.

Grey Relational Analysis

Rooting success depends on the combined performance of multiple rooting traits, so selecting a treatment based on single rooting trait can be misleading, so Grey Relational analysis (GRA) was applied to evaluate the rooting performance of teak clones, as this method is widely utilized for multi-response optimization where several factors simultaneously influence the performance. Because same treatment combination did not show uniform efficacy across all clones, GRA was used to identify the most effective auxin-concentration treatment combination that enhanced all the rooting traits including root initiation duration (*Supplementary Fig.* 1). As higher GRG value indicates superior overall performance, the GRG values calculated for all treatment combinations were used to rank each clone- treatment pair, enabling the identification of the optimal treatment for each clone (Table 6).

Considering all rooting parameters, the optimal treatment for improving the rooting performance of clones TG1 and TG2 was A2B2, which ranked highest among all treatments, and achieved a 100% rooting rate. Root initiation occurred within 5 days in TG1 within 10 days in TG2. For clone TG4, the A2B3 combination was identified as optimal, producing root initiation within 6 days and a 100% rooting rate, whereas the control treatment initiated rooting only after 8 days. The A2B1 combination was optimal for clones TG3, TG12 and TG20. Under this treatment, TG3 initiated roots within 7 days, and achieved a 90% rooting rate, clone TG12

initiated roots within 10 days and achieved 100% rooting rate, while TG20 showed 50% rooting with root initiation after 13 days under the same treatment.

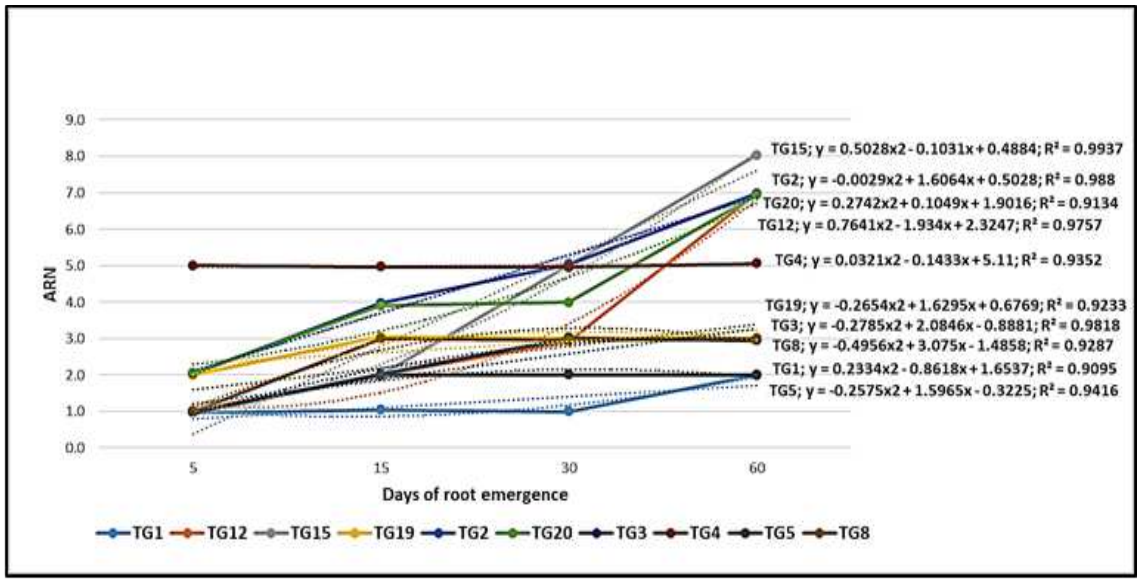
In clone TG15, the highest GRG value was recorded under the A3B4 treatment, with root initiation occurring within 13 days. Clone TG8, responded best to A1B3, root initiation occurred within 8 days and a 100% rooting rate. The A1B4 combination was optimal for clone TG5, also producing 100% rooting within 8 days. For clone TG19, the A1B1 combination was optimal, with a 50% rooting rate and root initiation occurring within 12 days, compared to 21 days in the control. Overall, Grey Relational Analysis demonstrated that the most effective treatment combinations varied among clones, but A2B-type combinations (particularly A2B1–A2B3) were frequently associated with earlier root initiation and higher overall rooting success across the majority of genotypes.

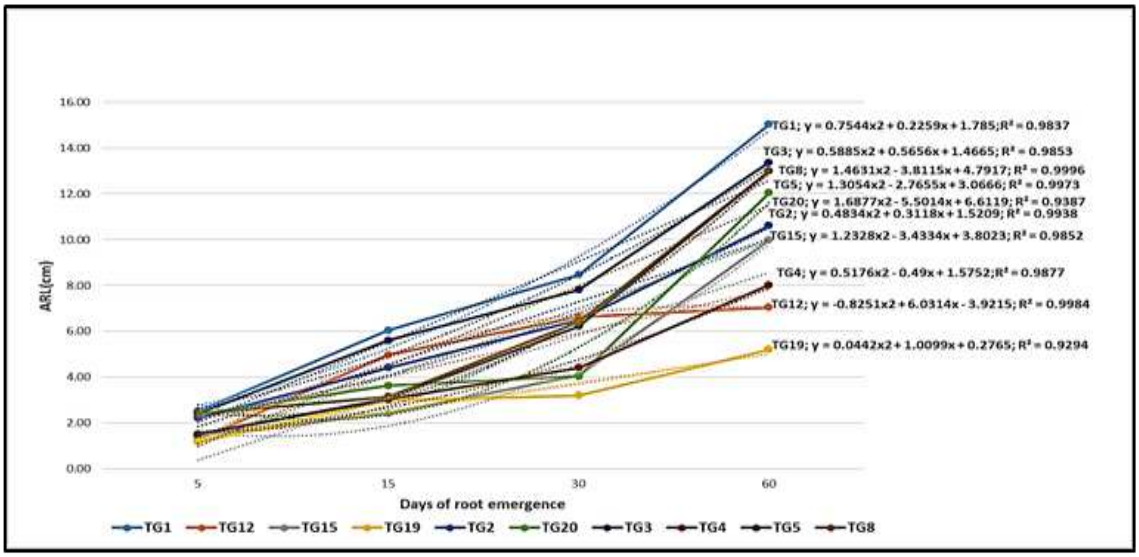
Table 6. Evaluation by Grey relational analysis based on the effects of different treatment combinations on ten clones rooting factors

Treatment	TG1	TG2	TG3	TG4	TG5	TG8	TG12	TG15	TG19	TG20
A1B1	0.569(9)	0.557(12)	0.609(8)	0.636(4)	0.683(5)	0.454(12)	0.672(3)	0.672(2)	**0.767(1)**	0.647(2)
A1B2	0.502(12)	0.569(11)	0.671(5)	0.521(9)	0.648(7)	0.562(6)	0.540(9)	0.538(8)	0.538(7)	0.578(5)
A1B3	0.558(10)	0.624(10)	0.483(12)	0.671(2)	0.685(4)	**0.807(1)**	0.535(10)	0.536(10)	0.441(11)	0.559(8)
A1B4	0.496(13)	0.625(9)	0.546(10)	0.544(8)	**0.815(1)**	0.517(10)	0.732(2)	0.579(7)	0.484(9)	0.567(7)
A2B1	0.703(6)	0.690(3)	**0.749(1)**	0.444(12)	0.648(8)	0.582(5)	**0.766(1)**	0.597(6)	0.553(6)	**0.894(1)**
A2B2	**0.873(1)**	**0.824(1)**	0.677(4)	0.551(6)	0.712(2)	0.625(3)	0.589(7)	0.531(11)	0.487(8)	0.636(3)
A2B3	0.805(2)	0.654(5)	0.637(7)	**0.775(1)**	0.641(9)	0.741(2)	0.535(11)	0.617(5)	0.573(4)	0.620(4)
A2B4	0.574(8)	0.650(6)	0.567(9)	0.650(3)	0.626(10)	0.562(7)	0.593(6)	0.632(4)	0.588(3)	0.573(6)
A3B1	0.751(4)	0.634(8)	0.529(11)	0.548(7)	0.598(11)	0.543(8)	0.585(8)	0.537(9)	0.441(10)	0.551(9)
A3B2	0.642(7)	0.648(7)	0.697(2)	0.408(13)	0.576(12)	0.458(11)	0.510(13)	0.475(12)	0.431(12)	0.492(11)
A3B3	0.794(3)	0.661(4)	0.431(13)	0.574(5)	0.685(3)	0.537(9)	0.520(12)	0.458(13)	0.414(13)	0.504(10)
A3B4	0.748(5)	0.529(13)	0.664(6)	0.455(11)	0.652(6)	0.381(13)	0.642(4)	**0.809(1)**	0.714(2)	0.375(13)
CWD4	0.545(11)	0.784(2)	0.690(3)	0.516(10)	0.562(13)	0.605(4)	0.638(5)	0.651(3)	0.556(5)	0.477(12)

Numbers in parentheses denote the rank assigned to each treatment according to the GRG. A lower rank number indicates superior overall performance

The time-course growth curves of each clone under their respective GRA-derived optimal treatment (Fig. 5) were consistent with the GRA ranking. Time-course regression analysis revealed a steady increase in all rooting traits from day 5 to day 60 across all clones. ARL, ARN, ARW, ANW, S and REI exhibited strong linear trends with high coefficient of determination (R^2>0.90), indicating a progressive and consistent improvement in rooting performance over time. Clones such as TG1, TG4 and TG12 for which IBA hormone was identfied as optimal treatment exhibited steep increase in most rooting traits. In contrast, clones such as TG19 and TG20, showed slower rate of increase, consistent with their lower rooting ability. These differences reflect inherent variation in rooting capacity among clones and their responsiveness to hormone treatments.





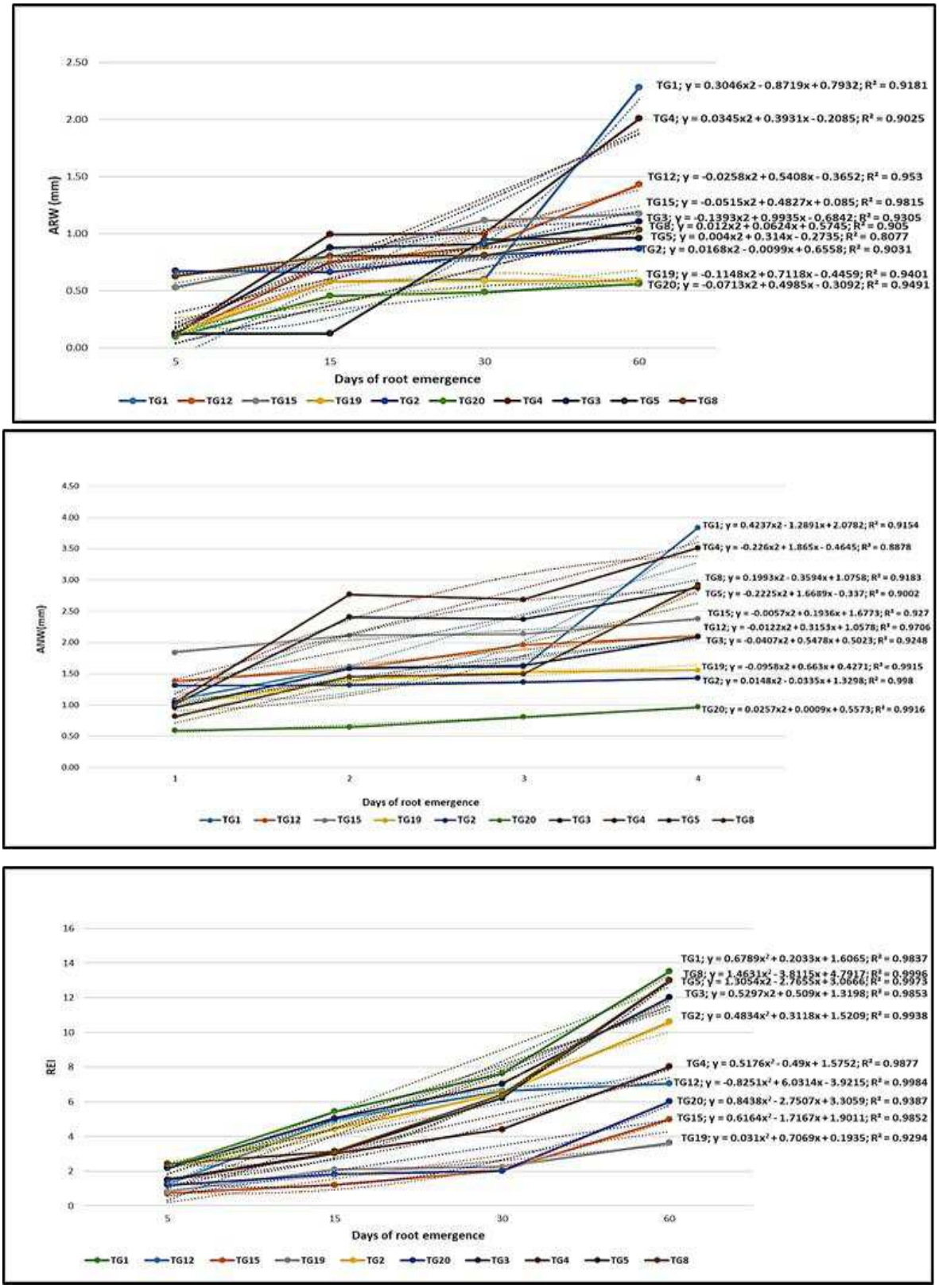


Figure 5. The rooting response curve of the ten teak genotypes subjected to the optimal treatment identified by grey relational analysis after 60 days of rooting period

The GRA heatmap (Fig. 6) provided a comparative overview of treatment performance across clones, clearly showing genotype-dependent variation in response to auxin treatments. Treatment within the A2B group (particularly A2B1-A2B3) consistently showed high GRA scores (red shading) across several clones, indicating superior overall performance. In contrast, control showed predominantly lower scores (blue shading), indicating poor rooting performance.

Clone specific responses were also evident: A1B3 showed the highest performance in TG8, A1B4 in TG5, while A3B4 in TG15. Clones TG1-TG4 exhibited strong responses across multiple treatments, suggesting broader hormonal responsiveness, whereas TG19 and TG20 showed mostly lower scores, indicating limited responsiveness. Overall, the heatmap demonstrates that although treatment efficacy is genotype-dependent, A2B-type treatments emerged as the most broadly effective across clones. Overall, the variation in auxin treatments and their effective concentrations across clones demonstrates that rooting performance is highly genotype-dependent, and that multi-trait evaluation is essential for accurately identifying the most suitable hormone treatment for each clone.

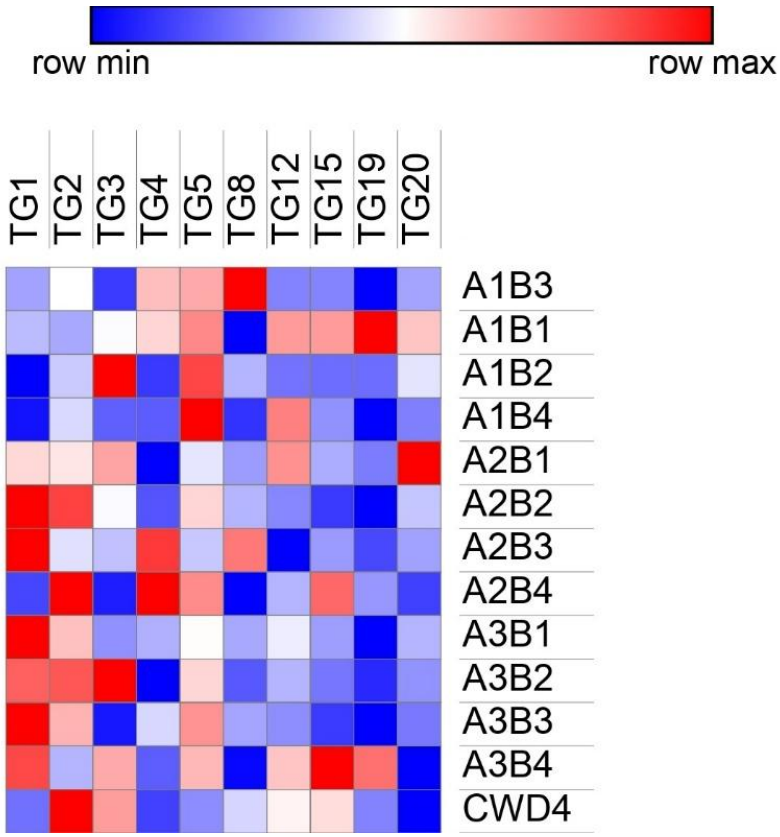


Figure 6. Heatmap of Grey Relational Grades

Discussion

Rooting stages in teak

The five-stage categorization of root development in teak micro-cuttings provides a clear framework for understanding the physiological and morphological progression of adventitious rooting. The early emergence phase (Stage I) reflects metabolic activation at the nodal region before visible root formation. Similar observations were reported by Warrier *et al*. (2022), who noted increased sugar and protein content during the initial days of root induction, suggesting that biochemical priming precedes visible root emergence. Stage II, characterized by root primordia protrusion, aligns with findings from Husen & Pal (2000), who emphasized the role of auxins in stimulating cell redifferentiation at nodal tissues. The appearance of milky white primordia within 5–15 days is consistent with the auxin-mediated initiation reported in hardwood cuttings.

Stage III, involving nodal swelling and adventitious root formation, corresponds to the rhizogenesis phase described by Metaxas *et al*. (2004), where auxin-treated tissues exhibited enhanced cell division and differentiation. The enlargement of the nodal region in teak micro-cuttings reflects the localized accumulation of growth regulators. Stage IV, marked by rapid elongation and increased root number, is strongly influenced by substrate conditions. Warrier *et al*. (2022) demonstrated that vermiculite as a substrate enhanced root thickness and elongation, while Mekala *et al*. (2026) reported survival rates up to 90% in *ex vitro* conditions when soil–sand–cocopeat–vermicompost mixtures were used. These findings highlight the importance of physical and nutritional support during elongation.

Stage V, the final stage, represents the maturation of roots with distinct brown coloration, indicating lignification and functional root system establishment. Comparable results were observed in *ex vitro* rooting studies by Mekala *et al*. (2026), where mature root systems ensured high acclimatization success. Control treatments in the present study exhibited delayed root emergence and fewer adventitious roots, a trend consistent with earlier reports that emphasized the necessity of exogenous auxin application for efficient rooting (Husen & Pal, 2000). These

results underscore the critical role of hormone treatments and optimized substrates in accelerating root initiation and ensuring robust root system development.

Influence of treatments on rooting in teak clones

Significant differences observed among clones for all rooting traits confirm the strong role of genotypic variability in determining rooting capacity in teak. Similar findings have been reported in clonal propagation studies of hardwoods, where genetic background influences rooting ability, root morphology, and survival rates (Husen, 2013; Mascarenhas and Muralidharan, 1993). This highlights the necessity of clone-specific protocols for successful micropropagation. Hormone type exerted a stronger influence on traits such as average root number (ARN), survival (S), root effect index (REI), average node width (ANW), and average root width (ARW). This is consistent with earlier reports that auxins, particularly indole-3-butyric acid (IBA), play a pivotal role in root initiation and proliferation (Warrier *et al*., 2022; Liu *et al*., 2025). The stronger effect of hormone type on ARN and REI suggests that auxin regulation is critical for both the quantity and physiological quality of roots formed. Concentration, on the other hand, had a more pronounced effect on average root length (ARL), as indicated by higher R-values. This agrees with studies showing that auxin concentration gradients influence elongation dynamics rather than initiation (Mekala *et al*., 2026; De Klerk, 2002).

Excessive hormone concentrations may inhibit elongation due to feedback regulation, while optimal levels stimulate sustained growth. Interaction effects between hormone and genotype, and between concentration and genotype, were significant for ARN and survival, but not for ARL, ARW, ANW, or REI. This suggests that while initiation and survival are highly genotype-dependent, elongation and thickness are more regulated by concentration and substrate conditions. Comparable genotype × hormone interactions have been documented in tropical tree species, reinforcing the complexity of rooting physiology (Mascarenhas and Muralidharan, 1993; Husen, 2013). Survival was influenced by all treatments and their interactions, underscoring the importance of integrating genotype selection, hormone type, and concentration optimization. Substrate and acclimatization conditions further modulate survival, as shown in *ex vitro* rooting studies where mixed soil substrates enhanced establishment success (Mekala *et al*., 2026). Hormone type is a dominant factor for most rooting parameters, while concentration is more

critical for root elongation. These results emphasize the need for a balanced approach: selecting responsive clones, applying the appropriate hormone type, and fine-tuning concentration levels to maximize rooting efficiency and survival.

Effect of hormone type and varying concentration on teak genotypes and their rooting traits

Auxin application, particularly IBA and NAA, enhanced root initiation and proliferation compared to control, confirming their role in stimulating adventitious root formation. The significant increase in average root number (ARN) under auxin treatments aligns with earlier studies in teak and other hardwoods, where exogenous auxins promoted root primordia development and improved rooting efficiency (Sawitri *et al*., 2020; Munir *et al*., 2021; Mekala *et al*., 2026). Although the control showed higher overall rooting percentages, hormone treated clones exhibited earlier root initiation, highlighting the temporal advantage of auxin application. This suggests that while untreated cuttings may eventually root, auxins accelerate the process, which is critical for commercial propagation. Variation in concentration influenced root elongation more strongly than initiation. Higher concentrations (750–1000 ppm) produced maximum ARN, but elongation (ARL) was more sensitive to concentration gradients, consistent with the findings of De Klerk (2002), who noted that auxin concentration primarily regulates initiation, while elongation depends on endogenous factors and substrate conditions.

Marked differences among clones in rooting traits such as ARL, ARW, ANW, and REI emphasize the genetic basis of rooting ability. Clones TG1, TG3, TG4, and TG8 consistently performed better across multiple parameters, while TG19 and TG20 were poor rooters. Such variability within a species has been widely documented in tropical trees, where genotype × hormone interactions determine rooting success (Liu *et al*., 2025; Husen, 2013). This highlights the importance of selecting responsive clones for clonal forestry programs. Although hormone treatments improved rooting traits, statistical grouping placed them within the same class as controls, suggesting that these traits are less hormone dependent and more influenced by genotype. The higher REI values in clones TG1 and TG3 reflect superior root system quality, which is critical for survival and field establishment. Comparable genotype specific differences in root morphology and quality indices have been reported in teak *ex vitro* rooting studies

(Mekala *et al*., 2026). Genotype, ultimately, remains the overriding factor across all traits, dictating the ultimate rooting capacity and quality.

Grey Relational Analysis (GRA)

Rooting in teak micro-cuttings is inherently multi-dimensional, involving traits such as rooting rate, root number, root length, thickness, node width, and root effect index. Selecting treatments based on a single trait can lead to biased conclusions, as improvements in one parameter may coincide with reductions in another. Grey Relational Analysis (GRA) addresses this limitation by integrating multiple traits into a composite Grey Relational Grade (GRG), thereby enabling holistic evaluation of treatment efficacy (Deng, 1982). The present study demonstrated that optimal treatments varied among clones, underscoring the importance of genotype-specific responses. For example, clones TG1 and TG2 performed best under A2B2, achieving rapid initiation (within 5–10 days) and 100% rooting. TG4 responded optimally to A2B3, while TG3, TG12, and TG20 showed improved rooting under A2B1, though TG20 remained a relatively weak rooter. These findings highlight that while A2B-type treatments were broadly effective, clone-specific optimization remains essential.

Such variability is consistent with earlier reports in clonal forestry. Saha *et al*. (2020) applied GRA to optimize auxin treatments in Eucalyptus cuttings and found that genotype × hormone interactions strongly influenced rooting outcomes, with different clones requiring distinct auxin concentrations for optimal root quality. Similarly, Saha *et al*., (2021) emphasized that GRA is particularly suited for multi-response optimization in plant tissue culture, where multiple morphological and physiological traits must be balanced. The frequent success of A2B-type treatments suggests that intermediate auxin concentrations provide a balance between initiation and elongation, avoiding the inhibitory effects of excessive hormone levels while ensuring sufficient stimulation of root primordia. This aligns with broader findings in adventitious rooting studies, where moderate auxin doses often yield superior root systems compared to either very high or very low concentrations (Saha *et al*., 2021; Kuo *et al*., 2008).

Importantly, GRA also captured differences in root initiation duration, a trait often overlooked in conventional analyses. Faster initiation, as observed in TG1, TG2, and TG4 under optimal

treatments, is advantageous for nursery management, reducing the time required for acclimatization and increasing efficiency in large-scale propagation. Comparable benefits of early initiation under optimized auxin treatments have been reported in Eucalyptus and other tropical hardwoods (Saha *et al*., 2020; 2021), reinforcing the utility of GRA in clonal propagation programs.

The integration of time-course growth curves and Grey Relational Analysis (GRA) provides deeper insight into the dynamics of rooting performance in teak clones. Regression analysis revealed strong linear trends ($R^2 > 0.90$) across all traits—root length, root number, root width, node width, survival, and root effect index—indicating progressive and consistent improvement over time. This confirms that rooting development under optimal treatments follows a predictable trajectory, with hormone responsiveness accelerating early initiation and sustaining growth. Clones such as TG1, TG4, and TG12, for which IBA was identified as the optimal treatment, exhibited steep increases in rooting traits, reflecting their high responsiveness to auxin stimulation. In contrast, TG19 and TG20 showed slower rates of increase, consistent with their lower rooting ability. These differences highlight the genotype-dependent variation in rooting capacity, a phenomenon widely reported in clonal forestry where genetic background strongly influences rooting success (Leakey, 2014; Husen & Pal, 2000; Saha *et al*., 2020).

The GRA heatmap provided a comparative overview of treatment performance across clones, clearly illustrating that A2B-type treatments (A2B1–A2B3) consistently achieved higher GRG scores, indicating superior overall performance. This supports earlier findings that intermediate auxin concentrations often yield balanced improvements across multiple rooting traits (Kuo *et al*., 2008; Saha *et al*., 2021). In contrast, control treatments showed predominantly lower scores, reinforcing the importance of exogenous auxin application for effective root induction.

Clone-specific responses were also evident: TG8 responded best to A1B3, TG5 to A1B4, and TG15 to A3B4. Meanwhile, clones TG1–TG4 exhibited strong responses across multiple treatments, suggesting broader hormonal adaptability. Conversely, TG19 and TG20 consistently showed lower scores, reflecting limited responsiveness. Such variability underscores the necessity of multi-trait evaluation methods like GRA, which avoid misleading conclusions based on single traits and instead identify the most suitable treatment for each genotype. Overall, the combined use of time-course regression and GRA demonstrates that rooting performance in teak

is highly genotype-dependent, with auxin type and concentration exerting differential effects across clones. While A2B-type treatments emerged as broadly effective, clone-specific optimization remains essential. These findings emphasize that multi-response optimization is critical for clonal forestry programs, ensuring efficient propagation strategies that maximize rooting success, survival, and overall plant quality.

GRA provides a systematic approach to identify the best treatment for each genotype, ensuring balanced improvement across rooting traits. This methodology offers a practical decision-making tool for teak clonal forestry, supporting the development of efficient, genotype-specific propagation strategies that maximize rooting success and survival.

Conclusion

This study highlights that rooting success in teak (*Tectona grandis*) micro-cuttings is strongly influenced by genotype, hormone type, and concentration. While auxin treatments, particularly IBA and NAA, accelerated root initiation and improved root number, clone-specific differences remained evident across all traits. Grey Relational Analysis (GRA) proved valuable in integrating multiple rooting parameters, identifying IBA treatments as broadly effective while also revealing unique optimal combinations for individual clones. Time-course regression confirmed consistent linear improvement in rooting traits, with high-performing clones showing rapid increases and weaker clones responding slowly. The GRA heatmap further emphasized genotype-dependent variation, reinforcing that no single treatment is universally optimal. Overall, these findings demonstrate the importance of multi-trait evaluation and clone-specific optimization in clonal forestry. By combining statistical analysis, GRA, and time-course assessment, this study provides a practical framework for developing efficient propagation strategies that enhance rooting success and survival in teak.

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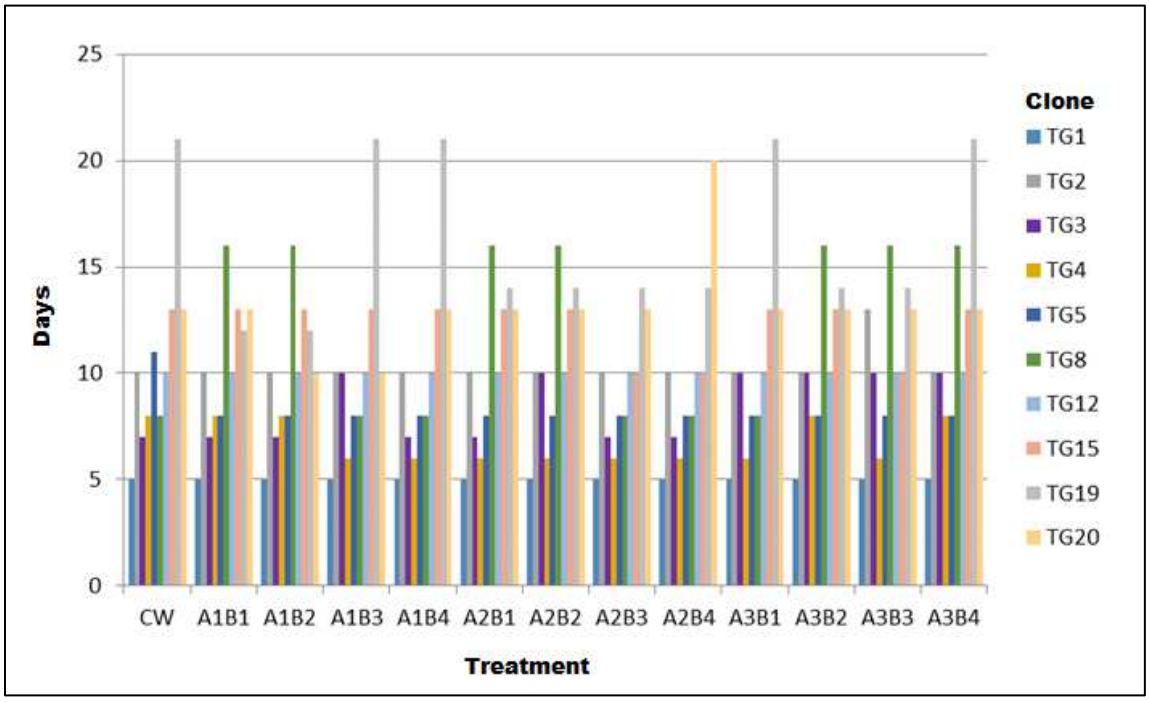

Supplementary Figure 1. Treatment effect on rooting initiation

Table S1. Descriptive statistic showing effect of treatment combinations on each rooting factor

Treatment	TG1	TG2	TG3	TG4	TG5	TG8	TG12	TG15	TG19	TG20
					ARN					
CW	1.25±0.5	2±0	1.5±0.58	1.75±0.5	2±1.16	1.5±0.58	2.25±0.96	2.75±1.26	1.5±0.58	1.75±0.5
A1B1	1.25±0.5	1.5±0.58	3±0.82	2.5±0.58	2.5±1	2.25±0.96	2.5±1	3±1.42	2.75±0.5	3.5±1.3
A1B2	1.25±0.5	2±0	2.5±1	2.75±0.5	1.75±0.5	2.25±0.96	2.75±0.5	2.25±1.26	3±1.42	2±0.82
A1B3	1.5±0.58	2±0	2.5±1	4±0	2.75±0.5	2.5±1	3.25±0.96	1.25±0.5	1.75±0.5	2.75±1.71
A1B4	1.25±0.5	2±0	2.5±1.3	2.75±0.5	1.75±0.5	2±0.82	4.25±2.22	2.25±0.5	1±0	3±0.82
A2B1	1.5±0.58	4.5±2.09	2.25±0.96	2.25±0.96	3.25±0.96	1.5±0.58	3.25±2.63	4.75±2.5	2±0.82	4.25±2.07
A2B2	1.25±0.5	2.5±0.58	2±0.82	4±1.16	2.5±0.58	3±0.82	3.5±1.92	3.25±2.07	3.25±1.5	4±2.17
A2B3	1.5±0.58	3.5±1.3	3.5±1.74	5±0	3±0	4±1.42	4±2.17	2.75±1.26	3±1.16	4.5±2.65

A2B4	2.25±0.96	2.5±1.74	3.25±0.96	6.75±3.78	2.25±0.96	2.25±0.96	4.5±2.52	4.25±2.07	2.5±1	3.75±1.71
A3B1	1.25±0.5	2.5±1	5.75±2.5	3.25±0.96	1.25±0.5	2.25±0.96	2.75±1.71	3.25±2.07	2±1.16	3.25±1.26
A3B2	2.25±0.96	3.75±2.07	5.75±3.41	4.5±1	2.5±0.58	2.5±1.3	2.5±0.58	3.5±1.92	2.5±1.3	2.5±1.3
A3B3	2.75±1.5	2.25±1.9	7.25±3.5	5±0	1.75±0.5	3±1.42	2.75±1.5	3.75±1.5	2.5±1	1.5±0.58
A3B4	2.75±1.5	1.5±0.58	6±3.56	5±0	2.25±0.5	1.5±1	3±2.17	4±3.17	0±0	0.01±0.01
					ARL					
CW	4.79±3.36	5.5±3.45	6.5±4.07	3.26±2.63	3.93±3.62	6.72±4.56	4.03±2.14	4.99±3.89	1.25±0.51	2.46±2.26
A1B1	7.25±4.2	4.14±2.37	5.56±3.36	5.28±3.74	4.71±4.13	7.13±4.6	5.01±2.61	5.42±4.03	3.13±1.65	3.92±2.51
A1B2	2.56±1.87	2.7±1.91	6.25±3.1	3.94±2.39	3.58±3.21	5.95±4.41	4.74±2.75	4.03±2.93	2.34±1.14	3.05±2.07
A1B3	4.32±3.19	3.31±2.44	6.17±3.66	4.55±2.87	6.25±4.99	6.24±4.83	4.7±2.57	3.08±2.42	1.19±0.53	2.59±1.82
A1B4	6.12±3.88	4.36±2.27	5.41±2.86	3.6±2.41	5.94±5.1	6.09±4.29	5.85±3	5.19±4.07	1.24±0.52	3.2±2.78
A2B1	8.13±5.1	2.14±1.85	7.3±4.62	3.6±2.38	3.32±2.71	7.33±5.27	4.97±2.65	3.25±2.33	3.4±2.03	5.52±4.4
A2B2	8.01±5.28	5.93±3.58	7.06±4.57	3.52±2.45	4.06±4.04	6.45±5.11	5.11±2.7	2.52±1.96	2.13±1.29	2.92±1.86
A2B3	7.5±4.9	3.12±2.05	6.29±3.69	4.23±2.8	3.6±3.17	7.02±4.96	3.27±1.87	3.2±2.64	2.61±1.26	2.41±1.45
A2B4	6.26±4.27	3.75±2.37	6.05±3.46	3.58±2.45	2.98±2.73	5.13±3.73	3.5±1.97	4.16±3.34	2.01±0.84	5.25±4.07
A3B1	7.08±5.88	2.69±1.7	6.9±4.12	3.54±2.44	3.87±3.07	6.28±4.6	4.7±2.53	4.67±3.69	2.21±1.6	2.39±1.42
A3B2	4.86±2.52	3.5±2.33	5.76±3.21	3.76±2.46	3.24±2.32	5.17±3.79	4.57±2.33	4±2.91	2.65±1.23	2.97±1.71
A3B3	5.55±4.15	2.71±1.68	5.62±2.93	3.54±2.4	5.46±4.94	7.07±4.64	3.81±1.98	3.11±2.19	2.74±1.48	2.13±1.1
A3B4	4.55±2.97	3.21±2.09	6.95±4.65	3.48±2.51	4.61±3.89	3.9±3.32	3.55±2.09	4.47±3.83	0±0	0±0
					S					
CW	90±0	100±0	100±0	100±0	100±0	80±0	100±0	70±0	80±0	30±0
A1B1	70±0	100±0	80±0	90±0	100±0	60±0	100±0	90±0	70±0	50±0
A1B2	70±0	100±0	90±0	100±0	100±0	100±0	80±0	50±0	50±0	40±0
A1B3	90±0	100±0	70±0	100±0	90±0	100±0	90±0	50±0	80±0	30±0
A1B4	40±0	100±0	80±0	100±0	100±0	70±0	90±0	40±0	10±0	30±0
A2B1	80±0	100±0	90±0	80±0	100±0	80±0	100±0	40±0	60±0	50±0
A2B2	90±0	100±0	100±0	90±0	100±0	100±0	90±0	40±0	30±0	40±0
A2B3	100±0	100±0	90±0	100±0	100±0	90±0	90±0	70±0	40±0	30±0
A2B4	60±0	100±0	80±0	90±0	100±0	90±0	90±0	40±0	50±0	20±0
A3B1	90±0	100±0	70±0	90±0	100±0	80±0	90±0	30±0	40±0	20±0
A3B2	100±0	100±0	90±0	80±0	100±0	70±0	80±0	20±0	40±0	30±0
A3B3	100±0	100±0	30±0	90±0	100±0	60±0	70±0	20±0	10±0	20±0
A3B4	90±0	90±0	80±0	90±0	100±0	60±0	90±0	50±0	0±0	0±0
					ARW					
CW	4.15±3.22	0.58±0.55	0.56±0.35	0.68±0.5	0.53±0.46	0.8±0.21	0.93±0.31	0.55±0.28	0.42±0.26	0.15±0.04
A1B1	0.71±0.51	0.45±0.29	0.78±0.17	0.81±0.53	0.84±0.55	0.73±0.19	0.91±0.53	0.43±0.24	0.48±0.23	0.31±0.15
A1B2	0.76±0.51	0.4±0.34	0.89±0.49	0.94±0.68	1±0.62	0.71±0.27	0.96±0.27	0.42±0.22	0.21±0.1	0.16±0.09
A1B3	0.84±0.68	0.6±0.36	0.74±0.43	0.96±0.64	0.48±0.41	0.83±0.17	0.84±0.17	0.72±0.41	0.54±0.29	0.17±0.09
A1B4	0.82±0.69	0.62±0.4	0.62±0.22	0.6±0.34	0.55±0.48	0.61±0.21	0.72±0.41	0.5±0.25	0.07±0.02	0.14±0.03
A2B1	0.78±0.44	0.83±0.29	0.76±0.44	0.7±0.41	0.73±0.42	0.66±0.41	0.8±0.55	0.59±0.31	0.65±0.49	0.41±0.21
A2B2	0.91±0.86	0.76±0.1	0.74±0.43	0.84±0.59	0.82±0.57	0.57±0.11	0.85±0.16	0.41±0.36	0.23±0.06	0.15±0.05
A2B3	0.9±0.95	0.76±0.14	0.87±0.17	1.04±0.77	0.79±0.5	0.63±0.15	0.71±0.17	0.64±0.37	0.38±0.31	0.12±0.02
A2B4	1.05±0.86	0.47±0.41	0.69±0.39	0.89±0.64	0.97±0.58	0.82±0.15	0.68±0.39	0.86±0.16	0.38±0.21	0.07±0.04
A3B1	0.84±0.54	0.57±0.54	0.71±0.4	0.9±0.66	0.8±0.48	0.73±0.15	0.78±0.46	0.36±0.18	0.28±0.13	0.08±0.06
A3B2	1.14±0.71	0.93±0.31	0.84±0.24	0.73±0.52	0.64±0.6	0.82±0.2	1.01±0.14	0.31±0.15	0.27±0.12	0.18±0.06
A3B3	0.94±0.77	0.5±0.46	0.51±0.35	0.67±0.5	0.76±0.4	0.75±0.29	0.76±0.44	0.42±0.07	0.06±0.04	0.12±0.01
A3B4	0.97±0.82	0.77±0.15	0.74±0.41	0.92±0.6	0.77±0.44	0.82±0.19	0.76±0.47	0.91±0.31	0±0	0±0
					ANW					
CW	1.63±0.56	1.5±0.62	1.62±0.51	2.42±0.99	1.63±0.81	1.33±0.51	1.65±0.17	1.46±0.36	1.16±0.2	0.33±0.04
A1B1	1.65±0.65	0.99±0.31	1.9±0.5	1.98±0.99	2.16±0.36	1.29±0.49	1.52±0.44	1.39±0.28	1.37±0.27	0.57±0.03
A1B2	1.8±0.61	1.44±0.46	1.53±0.65	1.93±0.65	2.07±0.74	1.04±0.46	1.49±0.23	1.34±0.37	1.73±0.59	0.49±0.04
A1B3	1.53±0.4	1.42±0.56	1.67±0.5	1.95±0.7	1.77±0.96	1.68±0.9	1.59±0.17	1.15±0.35	1.4±0.33	0.36±0.05
A1B4	1.98±0.84	1.39±0.5	1.51±0.4	1.76±0.51	2.17±0.81	1.25±0.54	1.58±0.39	1.28±0.24	0.5±0.34	0.51±0.33

A2B1	1.62±0.5	1.67±0.33	1.57±0.47	1.68±0.52	1.56±0.41	1.51±0.35	1.76±0.34	1.4±0.3	1.33±0.41	0.76±0.18
A2B2	2.04±1.24	1.36±0.06	1.78±0.54	2.32±0.91	1.55±0.66	1.33±0.53	1.69±0.38	1.25±0.36	1.29±0.22	0.65±0.28
A2B3	1.9±0.82	1.68±0.46	1.67±0.4	2.51±1.05	2.03±0.76	1.37±0.69	1.69±0.31	1.36±0.32	1.31±0.22	0.55±0.33
A2B4	1.96±0.78	1.42±0.54	1.71±0.47	2.3±0.94	1.83±0.53	1.3±0.4	1.54±0.48	1.54±0.31	1.43±0.44	0.42±0.38
A3B1	2.16±0.92	1.42±0.52	1.51±0.39	2.16±0.87	1.7±0.6	1.31±0.46	1.4±0.45	1±0.09	1.42±0.43	0.46±0.41
A3B2	1.96±0.96	1.7±0.16	1.81±0.67	2.12±0.66	1.27±0.34	1.28±0.5	1.43±0.22	0.79±0.21	1.57±0.4	0.35±0.06
A3B3	2.13±1.04	1.5±0.62	0.82±0.18	1.98±1.04	1.7±0.47	1.32±0.56	1.55±0.55	0.85±0.15	0.54±0.3	0.44±0.38
A3B4	2.18±1.07	1.43±0.54	1.81±0.52	2.25±0.53	1.85±0.68	1.19±0.47	1.62±0.59	2.12±0.23	0±0	0±0
					REI					
CW	4.31±3.02	5.5±3.45	6.5±4.07	3.26±2.63	3.93±3.62	5.38±3.66	4.03±2.14	3.49±2.72	1±0.41	0.74±0.68
A1B1	5.08±2.94	4.14±2.37	4.45±2.69	4.76±3.37	4.71±4.13	4.28±2.76	5.01±2.61	4.88±3.63	2.2±1.16	1.96±1.26
A1B2	1.8±1.31	2.7±1.91	5.62±2.79	3.94±2.39	3.58±3.21	5.95±4.41	3.79±2.21	2.01±1.47	1.17±0.57	1.22±0.83
A1B3	3.89±2.87	3.31±2.44	4.32±2.57	4.55±2.87	5.62±4.5	6.24±4.83	4.22±2.31	1.54±1.21	0.95±0.42	0.78±0.55
A1B4	2.45±1.56	4.36±2.27	4.33±2.29	3.6±2.41	5.94±5.1	4.26±3	5.26±2.7	2.08±1.63	0.13±0.06	0.96±0.84
A2B1	6.5±4.08	2.14±1.85	6.57±4.16	2.88±1.9	3.32±2.71	5.86±4.21	4.97±2.65	1.31±0.94	2.04±1.22	2.76±2.21
A2B2	7.21±4.76	5.93±3.58	7.06±4.57	3.17±2.21	4.06±4.04	6.45±5.11	4.6±2.43	1.01±0.79	0.64±0.39	1.17±0.75
A2B3	7.5±4.9	3.12±2.05	5.67±3.32	4.23±2.8	3.6±3.17	6.32±4.46	2.95±1.69	2.24±1.85	1.05±0.51	0.73±0.44
A2B4	3.76±2.56	3.75±2.37	4.84±2.77	3.22±2.21	2.98±2.73	4.62±3.36	3.15±1.77	1.67±1.34	1.01±0.42	1.05±0.82
A3B1	6.37±5.29	2.69±1.7	4.83±2.89	3.19±2.19	3.87±3.07	5.02±3.68	4.23±2.28	1.4±1.11	0.89±0.65	0.48±0.29
A3B2	4.86±2.52	3.5±2.33	5.18±2.89	3.01±1.97	3.24±2.32	3.62±2.65	3.66±1.87	0.8±0.58	1.06±0.5	0.89±0.52
A3B3	5.55±4.15	2.71±1.68	1.69±0.88	3.19±2.16	5.46±4.94	4.24±2.79	2.67±1.39	0.63±0.44	0.28±0.15	0.43±0.22
A3B4	4.1±2.67	2.89±1.89	5.56±3.72	3.13±2.26	4.61±3.89	2.35±1.99	3.19±1.88	2.24±1.92	0±0	0±0

Values are presented as Mean ± Standard deviation

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