GENETIC VARIATIONS OF 15 TEAK (*TECTONA GRANDIS*) CLONES PLANTED AT THE NORTHWESTERN AND NORTHEAST COAST OF PENINSULAR MALAYSIA

Nor-Fadilah Wook
Plant Improvement Programme, Forest Biotechnology Division,
Forest Research Institute Malaysia (FRIM), Kepong 52109, Selangor, Malaysia
Email: norfadilah@frim.gov.my

Mohd-Zaki Abdullah
Forest Biotechnology Division,
Forest Research Institute Malaysia (FRIM), Kepong 52109, Selangor, Malaysia
Email: zaky@frim.gov.my

Farah-Fazwa Md-Ariff
Plant Improvement Programme, Forest Biotechnology Division,
Forest Research Institute Malaysia (FRIM), Kepong 52109, Selangor, Malaysia
Email: farah@frim.gov.my

Sures Kumar Muniandi
Plant Improvement Programme, Forest Biotechnology Division,
Forest Research Institute Malaysia (FRIM), Kepong 52109, Selangor, Malaysia
Email: sures@frim.gov.my

Ahmad-Fauzi Mohd-Shariff
Plant Improvement Programme, Forest Biotechnology Division,
Forest Research Institute Malaysia (FRIM), Kepong 52109, Selangor, Malaysia
Email: afauzi@frim.gov.my

Muhammad-Asri Lias
Forest Plantation Programme, Forest Biotechnology Division,
Forest Research Institute Malaysia (FRIM), Kepong 52109, Selangor, Malaysia
Email: asrie@frim.gov.my

ABSTRACT

Tectona grandis, locally known as teak, is listed as one of the nine selected species in the forest plantation development program (PPLH) initiated by the Malaysian Timber Industry Board (MTIB) to ensure the sustainability of timber supply. However, even though teakwood is used worldwide for its alluring aesthetics and high economic value, not many industrial planters in Malaysia are willing to plant T. grandis due to the slow-growing nature of this species and the longer maturity period. Therefore, the selection process to ensure that only high-quality planting materials are planted in the forest plantations is very crucial. This long decade's study is conducted to provide high-quality planting sources of T. grandis that can grow optimally in Peninsular Malaysia. Progeny and clonal trials are vital to test the performance of different genotypes under local climates. During the early introduction in the 1950s, T. grandis was planted in the northern states of Malaysia (Perlis and Langkawi Island) and Sabah. A resource stand was established with provenances from Thailand, Indonesia, India, Papua New Guinea, Trinidad, and Sabah at FRIM Research Station (SPF) Mata Ayer, Perlis. Selected mother trees were then identified for the establishment of a clonal bank. This clone bank was listed in the Malaysia Book of Records in 2012 as 'The Largest Collection of Teak Clones in Malaysia'. The planting materials for the clonal trial study were obtained from this clone bank and mass-propagated via a budding technique (macro-propagation). The clonal trial plots were established at SPF Jeli (Kelantan) and SPF Mata Ayer in 2014. Assessment of the growth performances of eight years old data showed that based on the sites' comparison, there was a statistically significant difference ($p < 0.05$) on all the growth parameters tested, Diameter at Breast Height (DBH) and Total Height (HT) at 8 years old. An overview of the growth performance showed T. grandis planted at SPF Mata Ayer has a better growth performance. However, based on clonal variations, the differences are not significant except for the HT parameter. Clones-by-site interaction also showed no significant difference. Considering the good growth performances at the age of 8 years across the two locations, there were six best clones selected namely; T28, T3, T1, T8, T16 and T4. The mean annual increment (MAI) for DBH and HT of the clonal trial plot at the age of eight years is 1.6 cm/year and 1.3 m/year, respectively. These selected clones have the potential to be planted as forest plantations, consequently supporting an effort by the government to maintain the sustainable supply of wood materials.

Keywords: *selection, family, clones, variation, stability*

INTRODUCTION

Tectona grandis locally known in Malaysia as Jati or Teak (English) belongs to the family Lamiaceae. *T. grandis* is believed to have been introduced to Southeast Asia in the 14th century (Hansen et al., 2015), whereas the introduction of this species to Malaysia was around 1950s. *T. grandis* can be found naturally in countries such as Myanmar, India, Laos and Thailand which have tropical monsoon climates. Since this species can be considered highly adaptive to various environmental conditions, it is now can be found commercially in many regions. In addition, a study showed that *T. grandis* can grow optimally under high light intensity and higher annual rainfall (1200 – 1500 mm), which made this species also suitable to be planted in Malaysia (Hansen et al., 2015).

In short, a tree improvement program is the process of genetically improving a tree species (Hansen et al., 2015). Improvement programs may involve conventional tree breeding strategies such as progeny trials and clonal trials using selected genotypes obtained from natural selection and may also involve a genomics approach such as marker-assisted breeding. This process allowed the selection and production of improved growth rate, stem form, wood quality, pest and disease resistance genotypes and many other desirable characteristics of trees or plant species.

Tree improvement programs for *T. gandis* have been long conducted by other countries such as Thailand, India and Brazil. In Malaysia, even though *T. grandis* is listed as one of the species under the forest plantation development program (PPLH) initiated by the Malaysian Timber Industry Board (MTIB), not many industrial planters are willing to take the risk since this species has a longer maturity period of at least 45 years old (Hashim et al., 2015). In addition, the accessibility of high-quality planting resources is the main limiting factor in *T. gandis* plantation programs.

Thus, considering the high economic value of this species and its aesthetic wood qualities, Forest Research Institute Malaysia (FRIM) has taken the initiative to develop improvement programs for *T. grandis* to provide high-quality planting sources that can grow optimally in Peninsular Malaysia. The selection process to ensure that only high-quality planting materials are planted in the forest plantations is very crucial. Progeny and clonal trials are vital to test the performance of different genotypes under local climates. Studies have shown that genotypes selected from the progeny or clonal trials have an extra genetic gain of at least 5-25% as compared to the unselected or wild resources (Wu, 2019).

Moreover, FRIM plans to establish teak plantations using high-performing clones, to supply rural communities with a cheaper and sustainable source of teak wood. This will allow the expansion of the rural economy based on the production of handicrafts and furniture. The long-term goal is to create teak plantations with a shorter harvest cycle and higher yield, allowing for a continuous supply of teak wood.

MATERIALS AND METHODS

Plant materials

A total of 15 clones were macro-propagated via a budding technique, from a clone bank of *T. grandis* located at FRIM's research station (SPF) Mata Ayer, Perlis. The clone bank was established from the outcrossed seeds collected from a provenance resource stand which was established in 1974. The provenance resource stand was planted with teak provenances from Thailand, Indonesia, India, Papua New Guinea, Trinidad and Sabah. Selected mother trees were then identified for the establishment of a clonal bank in 1994. This clone bank was listed in the Malaysia Book of Records in 2012 as 'The Largest Collection of Teak Clones in Malaysia'. Planting materials for the clonal trial originated from this clone bank.

The clones were selected based on the plus trees criteria such as height, diameter at breast height, straightness and stem form. The clones were coded starting with T, B and A followed by the number coded for the specific clones. The difference among the three coded clones is the morphology of the leaves. For clones coded T, the leaves were shiny, smooth and darker green in colour resembling teak originating from India. For clones coded A, the leaves were coarse and had fine hair, whereas for clones coded B, the leaves were smooth and smaller than clones T and A, resembling the teak originating from Myanmar.

Clonal trial plots establishment

The clonal trial plots of *T. grandis* were established in June and August 2014 at FRIM's research station (SPF) Jeli (Kelantan) and SPF Mata Ayer (Perlis), respectively. Whereas the trial plot at SPF Selandar (Melaka) was established in October 2016. The trial plots were laid out in Randomized Complete Block Design (RCBD) with four replicates and four ramets per clone. Thus, making a total of 240 ramets (15 clones × 4 replicates × 4 trees) were planted with the distances of 4 m × 4 m, making the total plot areas 0.4 hectare/each. The trial plots were cleaned and maintained every three months.

Statistical Analysis

Growth data (height) were collected every three months during the first two years, and every six months at the age of three to five years old. The data of height (cm) were analysed at the age of 8 years old. The data were analysed by the Multivariate Analysis of Variance (ANOVA), followed by a Tukey post-hoc test using Statistical Package for the Social Sciences (IBM SPSS Statistics 22).

RESULTS AND DISCUSSION

Comparison of the growth performance of *T. grandis* at the age of 8 years old based on two different locations: SPF Jeli and SPF Mata Ayer

Initially, the clonal trial plots were established at three different locations (Figure 1); SPF Jeli (Kelantan), SPF Mata Ayer (Perlis) and SPF Selandar (Melaka). SPF Jeli is located in the northeastern of Peninsular Malaysia, whereas SPF Mata Ayer is located in the northwestern of Peninsular Malaysia. Early observation showed that the trees planted at SPF Selandar were stunted. SPF Selandar is located in the southern of Peninsular Malaysia. The growth performance at the age of one year old to 3 years old showed no apparent height increment (data not shown). Considering the financial and cost needed to maintain the plot, the data collection activities at SPF Selandar have been stopped since 2019 (the plot was established in 2016).

In terms of weather comparison, SPF Mata Ayer is similar to Thailand as it is much closer to Thailand where *T. grandis* can be found naturally. It has the lowest annual rainfall in Peninsular Malaysia and in the dry season, the temperature can go up as high as 40.0°C. Whereas SPF Jeli is located in the Kelantan state, the annual rainfall is higher and the mean annual temperature is lower as compared to SPF Mata Ayer. In addition, the two locations' soil series and geographical conditions differ (Table 1).

Table 1: Description of the trial locations

Location of the trial plots	SPF Jeli, Kelantan	SPF Mata Ayer, Perlis
State	Kelantan	Perlis
Latitude	N 5.6608186	N 6.653897
Longitude	E 101.7030933	E 100.241428
Soil series	Taitak and Renggam	Pokok Sena
Soil type	Silty, clay and loam	Clay and loam
Slope	Approximately 45° to 70°	Flat
Annual rainfall (mm)	2562 mm	2036 mm
Mean annual temperature (°C)	26.7 °C	27.3 °C

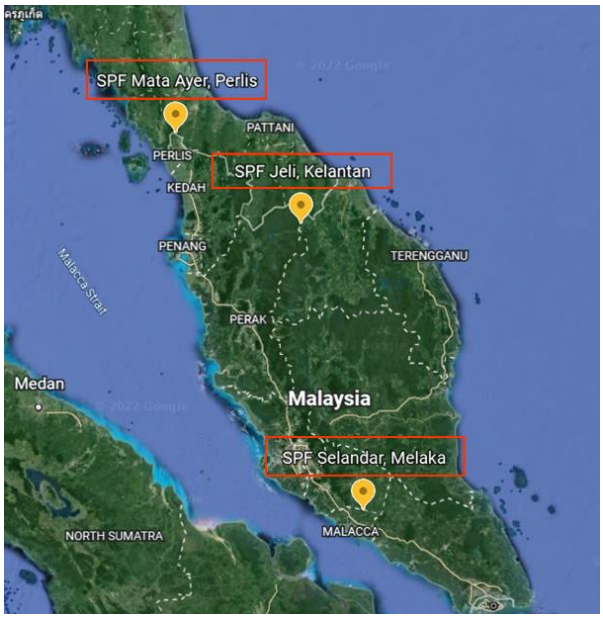

Figure 1: Location of the three clonal trial plots of *T. grandis*

Based on the location comparison, the Analysis of Variances (ANOVA) test revealed there was a significant difference ($p < 0.05$) for both tested growth parameters which are DBH and HT (Table 2). ANOVA test indicated that the location is a significant factor in the growth of *T. grandis*.

Table 2: Analysis of Variances (ANOVA) of Sites/location

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
DBH at 8 years old	205.816	1	205.816	9.490	.002
HT at 8 years old	242.280	1	242.280	19.578	.000

Table 3: Comparison of the growth performance of *T. grandis* at the age of 8 years old based on two different locations: SPF Jeli and SPF Mata Ayer

	Site	**Mean**	**± Std. Deviation**	**Survival rate (%)**
DBH at 8 years old	SPF Jeli	11.86	5.11	66.7
	SPF Mata Ayer	13.44	4.19	71.7
	Total	12.68	4.72	69.2
HT at 8 years old	SPF Jeli	9.46	3.86	66.7
	SPF Mata Ayer	11.17	3.17	71.7
	Total	10.35	3.62	69.2

Based on the growth performance at the age of 8 years old, *T. grandis* planted at SPF Mata Ayer showed the best performance. In terms of survival rates, SPF Mata Ayer scored 71.7%, whereas SPF Jeli scored 66.7% (Table 3). However, considering the location of SPF Jeli, which is located in forest areas where wildlife such as elephants can still be seen roaming the areas, the survival rate of *T. grandis* recorded in SPF Jeli is still considered as high. Initial data showed that the growth performance at SPF Jeli was better (data not shown), however at the age of 8 years old, both growth parameters taken indicated higher performance of SPF Mata Ayer. The mean DBH of *T. grandis* planted in SPF Mata Ayer recorded was 13.44 cm (Table 3) which was higher than 1.6 cm as compared to trees planted in SPF Jeli. Mean HT of SPF Mata Ayer recorded was significantly high which was 11.17 m as compared to SPF Jeli which was 9.46 m (Table 3). Considering there were 15 different clones tested in this study, the standard deviation recorded was considerably low, 4.19 to 5.11cm for DBH and 3.17 to 3.86 m for HT (Table 3). These values also indicated that clonal materials have much uniform growth as compared to seed-origin materials. Based on the recorded DBH and HT, it could be deduced that the mean annual increment (MAI) for DBH and HT of the clonal trial plot at the age of eight years range from 1.48 to 1.68 cm/year and 1.18 to 1.39 m/year, respectively.

Clonal teak trees have been found to have better growth performance compared to seed-origin trees. Research by Medeiros et al. (2019) reported that *T. grandis* clonal trees outperformed seed-origin trees by 50% in total volume and 48% in DBH. This is because clonal trees are able to capture both additive and non-additive genes, which results in better gains compared to trees propagated from plus trees (Hai et al., 2007). However, it also needs to be noted that the growth performance of both clonal and seed-propagated trees is not a constant, as phenotypic responses of genotypes in differing environmental conditions need to also be considered (Ding et al., 2008).

Table 4: Analysis of Variances (ANOVA) of Clones and Clones*Sites interaction

Source		Type III Sum of Squares	Df	Mean Square	F	Sig.
Clones	DBH at 8 years old	309.177	14	22.084	1.045	.408
	HT at 8 years old	332.809	14	23.772	2.068	.014
Clones*Sites	DBH at 8 years old	319.269	14	22.805	1.080	.376
	HT at 8 years old	191.141	14	13.653	1.187	.284

Based on the clones' comparisons, ANOVA tests revealed there was no significant difference ($p > 0.05$) in the growth performance of *T. grandis* planted at two locations except for the HT parameter ($p < 0.05$). As for the Clones by Sites interaction, both tested growth parameters (DBH and HT) showed no significant difference (Table 4).

Even though the ANOVA test showed a non-significant difference in the growth traits tested among the 15 clonal materials, there were 6 clones that recorded the mean DBH and HT above the grand mean (overall mean of both sites tested). The top six best clones are T28, T3, T1, T8, T16 and T4 (Figure 2). The survival rates recorded of all the 15 clones are more than 50% except for the clone T28 which recorded the lowest survival rate of 43.8%. However, clone T28 recorded the highest DBH. The highest survival rate is recorded by clone T24 (87.5%) and this clone also has good HT and DBH (Figure 2).

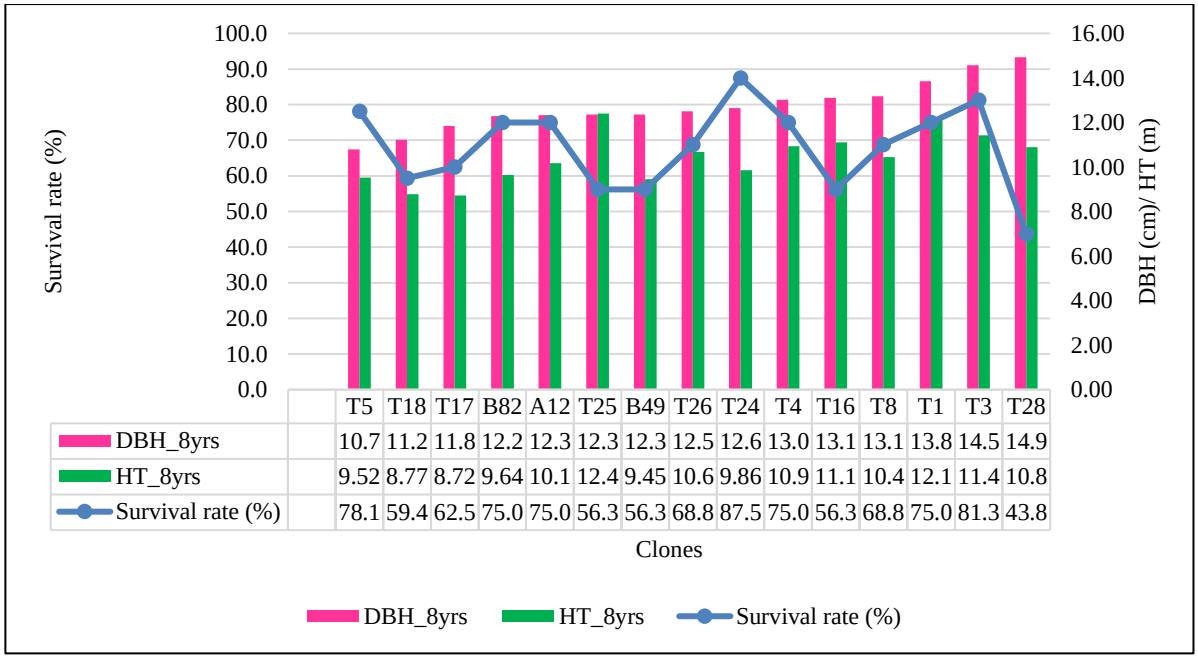

Figure 2: Mean of DBH and HT, and survival rate (%) at 8 years old (Overall: SPF Jeli & SPF Mata Ayer)

A study conducted in Costa Rica found that genotype by environment interaction (GxE) only accounted for 2.5% of the total phenotypic variation in *T. grandis* (Murilo et al., 2019). In this study, GxE (Clones* Sites) comparison also showed a non-significant difference but in term of site comparison, there was highly significant growth variations observed from the two sites tested. Nevertheless, as *T. grandis* is a species with diverse genetic variation, GxE could play a bigger role in different regions.

Comparison of the growth performance of *T. grandis* at the age of 8 years old at SPF Mata Ayer, Perlis

The comparison of growth performances among 15 clones of *T. grandis* at SPF Mata Ayer showed that there was no significant difference observed in both growth parameters tested. The grand mean for all the 15 clones tested for DBH was 12.8 cm, whereas for HT was 10.7 m. There were 5 clones in SPF Mata Ayer recorded mean DBH higher than the grand mean which are T3, T28, T1, B49 and T18 (Table 5). As for the HT, there were 6 clones recorded mean HT higher than the grand mean which are T25, T3, T28, T1, T26 and T4 (Table 6). Out of the five clones, T3 recorded a 100% survival rate together with T4. However, the growth performance of T4 in SPF Mata Ayer was not very promising. Even though, the ANOVA test revealed that the Clones*Sites interaction was not statistically significant, considering individual clone's performance at different site, T3 showed the best growth performance in SPF Mata Ayer, but was not in SPF Jeli (Table 5 and 6).

Table 5: Clones, Mean DBH (cm), Standard deviation (STDEV) and Survival rate (%)

Clones	Mean DBH (cm)	STDEV	Survival rate (%)
T3	16.34	5.09	100.0
T28	15.96	4.40	62.5
T1	14.01	4.81	75.0
B49	13.46	5.24	68.8
T18	13.19	4.31	62.5
T25	12.68	3.13	81.3
T24	12.68	4.63	93.8
T4	12.44	4.61	100.0
T26	12.39	4.26	87.5
T8	12.07	4.35	75.0
B82	11.76	5.33	87.5
A12	11.59	3.81	87.5
T5	11.21	2.40	75.0
T17	10.85	4.46	75.0
T16	10.46	4.02	62.5

Table 6: Clones, Mean HT (m), Standard deviation (STDEV) and Survival rate (%)

Clones	Mean HT (m)	STDEV	Survival rate (%)
T25	12.53	2.74	81.3
T3	12.31	2.86	100.0
T28	11.90	2.44	62.5
T1	11.58	3.87	75.0
T26	11.29	4.10	87.5
T4	10.78	3.75	100.0
B49	10.62	2.74	68.8
T18	10.43	3.45	62.5
T24	10.25	3.63	93.8
T16	10.23	3.94	62.5
T5	10.13	2.22	75.0
B82	9.66	4.11	87.5
T8	9.63	4.20	75.0
T17	9.43	3.39	75.0
A12	9.07	3.15	87.5

Comparison of the growth performance of *T. grandis* at the age of 8 years old at SPF Jeli, Kelantan

The comparison of growth performances among 15 clones of *T. grandis* at SPF Jeli also showed that there was no significant difference observed in both growth parameters tested. The grand mean for all the 15 clones tested for DBH was 9.9 cm, whereas for HT was 8.3 m. There were 7 clones in SPF Jeli recorded mean DBH higher than the grand mean which are T17, A12, T24, T16, T1, T8 and T4 (Table 7). As for the HT, there were 6 clones that recorded mean HT higher than the grand mean which are T1, T17, T16, T4, T24 and A12 (Table 6). The highest survival rate was recorded by clone T24 which was 93.8%. Even though, the ANOVA test revealed that the Clones*Sites interaction was not statistically significant, considering individual clone's performance at different site, T17 showed the best growth performance in SPF Jeli, but was not in SPF Mata Ayer (Table 7 and 8).

Table 7: Clones, Mean DBH (cm), Standard deviation (STDEV) and Survival rate (%)

Clones	Mean DBH (cm)	STDEV	Survival rate (%)
T17	12.18	4.99	68.8
A12	11.18	3.78	75.0
T24	11.00	4.19	93.8
T16	10.95	4.43	81.3
T1	10.70	4.71	87.5
T8	10.50	7.53	81.3
T4	10.41	3.94	68.8
B82	9.68	3.59	81.3
T25	9.57	4.97	62.5
T28	9.51	4.74	56.3
T5	9.24	5.01	87.5
T3	8.87	4.57	75.0
B49	8.68	4.36	62.5
T26	8.35	6.25	75.0
T18	7.52	2.99	68.8

Table 8: Clones, Mean HT (m), Standard deviation (STDEV) and Survival rate (%)

Clones	Mean HT (m)	STDEV	Survival rate (%)
T1	10.96	3.70	87.5
T17	9.55	3.33	68.8
T16	9.16	3.94	81.3
T4	9.12	3.00	68.8
A12	8.98	2.97	75.0
T24	8.47	2.58	93.8
B82	8.02	2.37	81.3
T8	8.02	4.38	81.3
T5	7.97	4.33	87.5
T25	7.84	3.22	62.5
T26	7.43	3.74	75.0
T3	7.33	2.40	75.0
T28	6.86	2.70	56.3
B49	6.74	3.66	62.5
T18	6.41	2.71	68.8

CONCLUSION

An overview of the growth performance showed *T. grandis* planted at SPF Mata Ayer has a better growth performance. It was not significant during earlier age but after 8 years old, the growth performances of *T. grandis* planted in the northwestern part of Peninsular Malaysia demonstrated obvious changes in growth rates. In terms of clonal variations, the differences in growth performance were considered as not significant. Clones-by-site interaction also showed no significant difference. However, considering the good growth performances at the age of 8 years across the two locations, there were six best clones selected namely; T28, T3, T1, T8, T16 and T4. These selected clones have the potential to be planted as forest plantations, consequently supporting an effort by the government to maintain the sustainable supply of wood materials.

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