

Variation in Stem Straightness and Wood Basic Density of *Tectona grandis* Provenances at Longuza Forest Plantation, Tanzania

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Abstract

Stem straightness and wood basic density are crucial characteristics influencing the wood quality, commercial value, and utilization of *Tectona grandis* (Teak) timber, yet variation in these traits among provenances remains poorly studied, particularly in Tanzania. This study assessed wood quality based on stem straightness and basic density variation across 12 Teak provenances established on the same site in 2011 at Longuza Forest Plantation, Tanzania. The trial was laid out in a randomized complete block design with 8 replications, each plot containing 6 trees. Stem straightness was measured non-destructively using a scoring method (1 = best, 4 = worst), while basic density was determined through standardized laboratory testing of extracted core samples. Statistical analysis was performed in SAS® 9.4, using mixed models with provenance fitted as a fixed effect and replicate block and family nested within provenance fitted as random effects, to account for the trial's design structure. Stem straightness did not vary significantly among the 12 provenances ($F(11,29) = 1.56$, $p < 0.163$), although East Africa Mtibwa (1.81 ± 0.76), CSIRO Thailand (1.82 ± 0.80), and East Africa Longuza seed stand (1.82 ± 0.80) had the numerically best mean scores. Basic density showed a provenance effect approaching conventional significance ($F(11,238) = 1.79$, $p < 0.056$), with East Africa Longuza Progeny Trial ($0.545 \pm 0.071 \text{ g cm}^{-3}$) significantly denser than CSIRO Thailand ($0.469 \pm 0.053 \text{ g cm}^{-3}$; Tukey-adjusted $p < 0.015$), no other pairwise comparison was significant. Average basic density across provenances was $0.517 \pm 0.059 \text{ g cm}^{-3}$. These findings show that, at 11 years of age, provenance level differences in stem straightness are modest relative to tree to tree variation within families, while basic density shows a more defensible, if still limited, provenance level signal. Given the modest and uneven replication across prov-

enances, selection decisions should be made cautiously, with re-assessment recommended as the trial matures.

Keywords

Tectona grandis, Provenance Trial, Wood Quality, Tanzania

1. Introduction

Teak (*Tectona grandis*) is a highly valued tropical hardwood known for its exceptional strength, durability, and aesthetic values. Its versatility and wide range of applications make it a popular choice for various purposes, including furniture, flooring, boat building, and construction (Kollert & Cherubini, 2012). The quality and suitability of Teak wood are influenced by several factors, including stem straightness and physical properties (Adi et al., 2016). Stem straightness is a crucial characteristic in Teak trees as it determines the quality and usability of the harvested timber (Kollert & Kleine, 2017). A straight stem ensures minimal waste during sawing and provides higher-quality boards and veneers (Evans & Turnbull, 2004). Moreover, it facilitates efficient processing and enhances the overall value of the timber. In addition to stem straightness, the physical properties of Teak wood play a vital role in determining its suitability for specific applications. Physical properties such as basic density have a positive correlation with mechanical properties of wood that influence the strength, durability, and workability of the wood (Amoah & Inyong, 2019; Hidayati et al., 2015).

Although, the most common parameters measured in provenance trials are height and diameter, as easily obtainable measures of growth, wood density is often measured as a wood quality parameter (Nabais et al., 2018). Understanding the variation in stem straightness and physical properties among different Teak provenances is of significant importance for determination of wood quality, and optimizing the use of Teak wood in different industries, ensuring its quality and long-term performance (Evans & Turnbull, 2004; Kokutse et al., 2004).

Several researchers around the world have undertaken research on stem straightness and physical properties variations of Teak. These studies used both destructive and non-destructive approaches, providing valuable insights into the field. Remarkable studies include the work of Madoffe and Maghembe (1988), Pedersen et al. (2007), Moya and Marin (2011), and Hidayati et al. (2015) at different ages of 10, 17 and 30 years old. Despite these significant research efforts, it remains clear that the level of knowledge concerning the stem straightness and wood basic density of Teak is currently insufficient to provide recommendations for the selection of a seed source when establishing plantations beyond its natural range, as noted by Kjær et al. (2011). Furthermore, the research specifically focusing on 11-year-old Teak provenances, particularly within the context of Tanzania, remains relatively scarce. This highlights the need for further exploration and analysis in

this specific field to enhance our knowledge of Teak's stem straightness and physical properties variations in Tanzania.

The study aims to address these aspects by conducting an assessment of stem straightness and wood basic density variation in a diverse range of Teak provenances. The findings of this study will serve as a valuable resource for stakeholders in the Teak industry, in choosing suitable provenance for breeding programmes, timber industries and end uses. This information will also enable decision-making and sustainable utilization of Teak resources that supports both conservation and economic goals.

2. Materials and Methods

2.1. Site Description

The study was conducted in Tanzania Forestry Research Institute (TAFORI) trial plots situated within the Longuza Forest Plantation, located in the Northeastern of Tanzania, between latitudes $40^{\circ}55'$ and $50^{\circ}10'$ South, and longitudes $38^{\circ}40'$ and $39^{\circ}00'$ East. The study area is elevated between 160 and 560 m above sea level, positioned on the foothills of the Eastern Usambara Mountains, in close proximity to the Amani Nature Reserve. It is approximately 52 km away from Tanga City (**Figure 1**). The topography of the area is characterized by a moderate slope with a gradient ranging from 10% to 15%, frequently intersected by numerous perennial and periodic streams. The soil composition predominantly consists of dark brown and red soils, with some areas containing clay soil. The area experiences two distinct seasons: the long rainy season (March to May) and the short rainy season (October to December). The area's mean annual rainfall and temperature are approximately 1500 mm and 27°C , respectively (Zahabu et al., 2015).

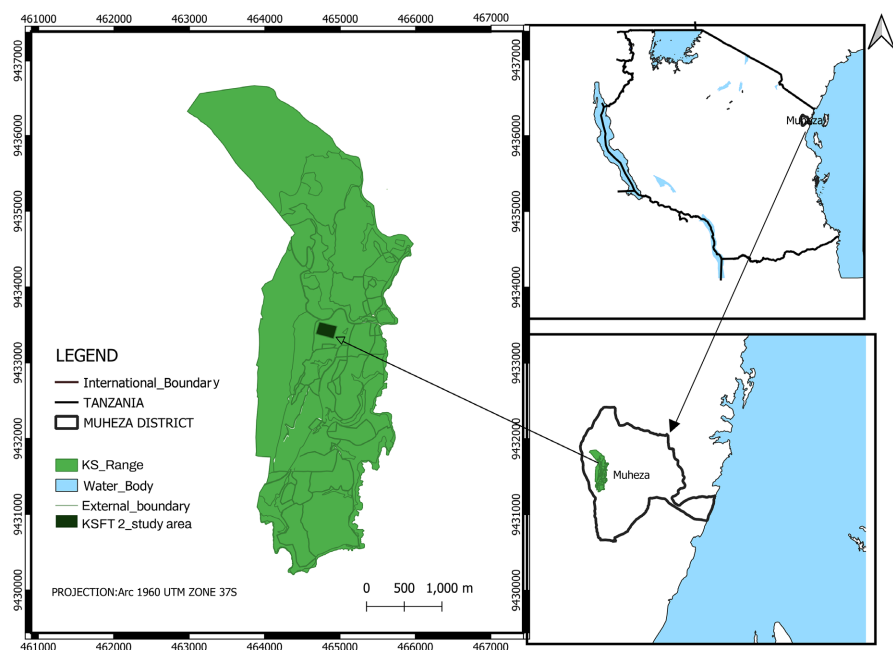


Figure 1. Maps showing study area at Longuza Forest Plantation. Source: Author (2022).

2.2. Teak Provenance Seed Origins

The Teak provenance seeds used in this trial were sourced from various locations, representing different seed origins represented by 41 families. The origins of the 12 teak provenance seeds are provided in **Table 1** (Hansen et al., 2017; Kollert & Kleine, 2017).

Table 1. *Tectona grandis* provenances assessed at Longuza Forest Plantation.

Country	Provenance name	Provenance code	Family code	Latitude	Longitude	Altitude (m)
Colombia	Refocosta seed stand	2	101	10°01'N	74°12'W	950
Colombia	Refocosta seed stand	2	202	10°01'N	74°12'W	950
Colombia	Refocosta seed stand	2	206	10°01'N	74°12'W	950
Colombia	Refocosta seed stand	2	208	10°01'N	74°12'W	950
Colombia	Refocosta seed stand	2	210	10°01'N	74°12'W	950
Colombia	Refocosta seed stand	2	213	10°01'N	74°12'W	950
Tanzania	East Africa Longuza progeny trial	3	301	5°12'S	38°39'E	200
Tanzania	East Africa Longuza progeny trial	3	302	5°12'S	38°39'E	200
Tanzania	East Africa Longuza progeny trial	3	303	5°12'S	38°39'E	200
Tanzania	East Africa Longuza progeny trial	3	304	5°12'S	38°39'E	200
Tanzania	East Africa Longuza provenance trial	4	401	5°12'S	38°39'E	200
Tanzania	East Africa Longuza provenance trial	4	402	5°12'S	38°39'E	200
Tanzania	East Africa Longuza provenance trial	4	403	5°12'S	38°39'E	200
Tanzania	East Africa Longuza provenance trial	4	501	5°12'S	38°39'E	200
Tanzania	East Africa Longuza provenance trial	4	503	5°12'S	38°39'E	200
Tanzania	East Africa Longuza seed stand	5	510	5°12'S	38°39'E	200
Tanzania	East Africa Mtibwa	6	601	6°08'S	37°38'E	460
Tanzania	East Africa Mtibwa	6	602	6°08'S	37°38'E	460
Tanzania	East Africa Mtibwa	6	603	6°08'S	37°38'E	460
Tanzania	East Africa Kihuhwi seed stand	7	701	5°12'S	38°39'E	200
Tanzania	East Africa Kihuhwi seed stand	7	702	5°12'S	38°39'E	200
Indonesia	Sumalindo	9	901	1°24'S	118°19'E	70 - 80
Indonesia	Sumalindo	9	903	1°24'S	118°19'E	70 - 80
Indonesia	Sumalindo	9	905	1°24'S	118°19'E	70 - 80
Indonesia	Sumalindo	9	909	1°24'S	118°19'E	70 - 80

Continued

Costa Rica	DeGuate-Tailandia	12	1106	14°15'N	91°29'W	60
Costa Rica	DeGuate-Tailandia	12	1107	14°15'N	91°29'W	61
Costa Rica	DeGuate-Tailandia	12	1109	14°15'N	91°29'W	62
Costa Rica	DeGuate-Tailandia	12	1110	14°15'N	91°29'W	63
Thailand	CSIRO Thailand	16	1605	16°20'N	97°101'E	2590
Thailand	CSIRO Thailand	16	1607	16°20'N	97°101'E	2590
Thailand	CSIRO Laos	17	1705	13°54'N	107°59'E	1500
Thailand	CSIRO Laos	17	1706	13°54'N	107°59'E	1500
Thailand	CSIRO Laos	17	1707	13°54'N	107°59'E	1500
Thailand	CSIRO Laos	17	1708	13°54'N	107°59'E	1500
Thailand	CSIRO Laos	17	1709	13°54'N	107°59'E	1500
Thailand	CSIRO Laos	17	1710	13°54'N	107°59'E	1500
Thailand	CSIRO Laos	17	1711	13°54'N	107°59'E	1500
Mozambique	Chikweti Niasa-Lichinga	19	1901	15°28'S	15°28'S	700
Mozambique	Chikweti Niasa-Lichinga	19	1904	15°28'S	15°28'S	700
Venezuela	SKCV Bulk	98	2001	7°16'N	70°55'W	330

CSIRO = Commonwealth scientific and industrial research organisation of the Australian government.

2.3. Experimental Design

The trial was established on May 2, 2011. The plots were arranged using a complete randomized block design consisting of 8 replications, 16 blocks, and 256 plots. Each plot accommodated 6 trees, spaced at 2.5 m × 2.5 m, resulting in a total of 96 trees per block and 192 trees per replication. To mitigate edge effects, the trial was bordered by two rows of the same species, ensuring consistency with the prevailing species composition within the trial. The experimental layout and map of the trial can be observed in **Table 2** and **Figure 2** respectively.

Table 2. Study area trial layout.

Replication	Block	Plot range
Rep 1	Block 1	Plots 1 to 16
Rep 1	Block 2	Plots 17 to 32
Rep 2	Block 1	Plots 33 to 48
Rep 2	Block 2	Plots 49 to 64
Rep 3	Block 1	Plots 65 to 80

Rep 3	Block 2	Plots 81 to 96
Rep 4	Block 1	Plots 97 to 112
Rep 4	Block 2	Plots 113 to 128
Rep 5	Block 1	Plots 129 to 144
Rep 5	Block 2	Plots 145 to 160
Rep 6	Block 1	Plots 161 to 176
Rep 6	Block 2	Plots 177 to 192
Rep 7	Block 1	Plots 193 to 208
Rep 7	Block 2	Plots 209 to 224
Rep 8	Block 1	Plots 225 to 240
Rep 8	Block 2	Plots 241 to 256

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to their straightness, branching patterns, and the presence of slight bends and crookedness using the scoring method, 1 being the best and 4 the worst (**Table 3**). From each plot, one tree free from observable defects was selected for basic density determination. Cores were then extracted from the selected trees using a wood increment borer. Based on ISO 13061-1: 2014, the collected samples were immersed in clean water to restore them to their green volume condition. Once the samples had regained this state, the law of flotation was applied to determine their green volume. Subsequently, the samples were dried in an oven ($102^{\circ}\text{C} \pm 3^{\circ}\text{C}$) until a constant weight was attained. After allowing the samples to cool in a desiccator they were reweighed and the measurements were recorded. The basic density was calculated by dividing oven dry weight by green volume.

Table 3. Description of stem straightness scores.

S/n	Description of stem quality class	Class
1	Straight to the top and good stem form	1
2	Straight and good stem form but with straight top forks	1
1	Straight and good stem form but with one slight bend less than 1 m in length	2
2	Straight and good stem form but with slightly bent or crooked mid/top forks	2
3	Straight and good stem form but with buttresses within 1 m height	2
1	Slight bends less than 1 m at bottom and at top with straight middle part	3
2	One slight bend more than 1 m in length	3
3	Slight crook, slight taper, buttressed within 2 m height	3
1	Serious crook, excess taper and buttressed beyond 2 m height	4

2.5. Data Analysis

Stem straightness (an ordinal score from 1 to 4) was analysed using a cumulative-logit mixed model (PROC GLIMMIX, SAS 9.4), with provenance fitted as a fixed effect and replicate block (Rep) and family nested within provenance (Fam (Prov)) fitted as random effects, in order to respect the trial's randomized complete block design and the nesting of 41 families within 12 provenances. Since least-squares means are not available for the multinomial distribution in PROC GLIMMIX, the same model structure was additionally fitted to rank-transformed straightness scores using PROC MIXED (REML estimation, Kenward-Roger degrees of freedom), which provided Tukey-Kramer-adjusted pairwise comparisons among provenance least-squares means. Wood basic density was analysed using a linear mixed model (PROC MIXED, REML estimation, Kenward-Roger degrees of freedom), with provenance as a fixed effect and Rep and Fam (Prov) as random effects. Where the fixed effect of provenance was significant or approached significance, Tukey-Kramer-adjusted pairwise comparisons among provenance least-squares means were used to identify the specific provenances that differed.

3. Results

3.1. Stem Straightness

A total of 730 of the 1536 trees originally planted were alive and assessed for stem straightness at 11 years of age (**Table 4**); the remainder had been lost to normal mortality over the course of the trial. Stem straightness did not differ significantly among the 12 provenances (cumulative-logit mixed model: $F(11,29) = 1.56$, $p < 0.163$; a rank-transformed mixed model gave a consistent result: $F(11,30.1) = 1.56$, $p < 0.163$; **Table 5**). No pairwise provenance comparison was significant after Tukey-Kramer adjustment (**Table 6**).

Descriptively, East Africa Mtibwa (1.81 ± 0.76), CSIRO Thailand (1.82 ± 0.80), and East Africa Longuza seed stand (1.82 ± 0.80) had the numerically lowest (straightest) mean scores, while CSIRO Laos had the highest (2.27 ± 0.84), consistent in direction with previous reports (Pedersen et al., 2007) even though the difference was not statistically significant here. About 66.98% of trees scored 1 or 2, while 33.02% scored 3 or 4. Variance components from the rank-transformed model indicated that block and family(provenance) each accounted for a modest share of total variance (2.5% and 2.2%, respectively), with the great majority of variation (95.3%) occurring among individual trees within families (**Table 7**). **Table 8** displays the descriptive mean ($\pm$ SD) straightness score of families within the study.

Table 4. Number of trees assessed for stem straightness and cores processed for basic density, by provenance.

Provenance code	Provenance name	N trees (straightness)	N cores (density)
2	Refocosta seed stand	110	38
3	East Africa Longuza Progeny Trial	84	30
4	East Africa Longuza Provenance Trial	98	35
5	East Africa Longuza seed stand	22	8
6	East Africa Mtibwa	53	18
7	East Africa Kihuhwi seed stand	47	16
9	Sumalindo	58	21
12	DeGuate-Tailandia	80	28
16	CSIRO Thailand	38	13
17	CSIRO Laos	101	35
19	Chikweti Niasa-Lichinga	17	6
98	SKCV Bulk	22	8
Total		730	256

CSIRO = Commonwealth scientific and industrial research organisation of the Australian government.

Table 5. Results of mixed-model tests for variables measured at the site.

Variable	Model	Num DF	Den DF	F	<i>p</i> -value	Significant
Stem straightness	Ordinal (cumulative logit) mixed model, Prov fixed/Rep + Fam (Prov) random	11	29	1.56	0.163	No
Basic density	Linear mixed model (REML, Kenward-Roger), Prov fixed/Rep + Fam (Prov) random	11	238	1.79	0.056	No (borderline)

Df = Degrees of freedom.

Table 6. Descriptive stem straightness scores by provenance at site.

Provenance code	Country	Provenance name	N	Mean score $\pm$ SD
6	Tanzania	East Africa Mtibwa	53	1.81 $\pm$ 0.76
16	Thailand	CSIRO Thailand	38	1.82 $\pm$ 0.80
5	Tanzania	East Africa Longuza seed stand	22	1.82 $\pm$ 0.80
12	Costa Rica	DeGuate-Tailandia	80	1.84 $\pm$ 0.80
4	Tanzania	East Africa Longuza Provenance Trial	98	1.88 $\pm$ 0.86
3	Tanzania	East Africa Longuza Progeny Trial	84	1.92 $\pm$ 0.91
2	Colombia	Refocosta seed stand	110	1.96 $\pm$ 0.89
7	Tanzania	East Africa Kihuhwi seed stand	47	2.02 $\pm$ 0.79
98	Venezuela	SKCV Bulk	22	2.09 $\pm$ 0.81
19	Mozambique	Chikweti Niasa-Lichinga	17	2.12 $\pm$ 0.60
9	Indonesia	Sumalindo	58	2.16 $\pm$ 0.85
17	Thailand	CSIRO Laos	101	2.27 $\pm$ 0.84

SD = Standard deviation; CSIRO = Commonwealth scientific and industrial research organisation of the Australian government.

Table 7. Variance components (share of total variance) from the design based mixed models.

Trait	Rep (block)	Fam (Prov)	Residual (tree to tree)
Stem straightness (rank scale)	2.5%	2.2%	95.3%
Basic density	7.0%	0.0% (boundary estimate)	93.0%

Table 8. Stem straightness mean score of *Tectona grandis* families in the study site.

Family code	Country	Family name	N	Mean score $\pm$ SD
603	Tanzania	East Africa Mtibwa	19	1.53 $\pm$ 0.70
1107	Costa Rica	DeGuate-Tailandia	16	1.56 $\pm$ 0.73
403	Tanzania	East Africa Longuza Provenance Trial	21	1.57 $\pm$ 0.68
501	Tanzania	East Africa Longuza Provenance Trial	20	1.60 $\pm$ 0.82

Continued

210	Colombia	Refocosta seed stand	8	1.63 ± 0.92
1607	Thailand	CSIRO Thailand	14	1.64 ± 0.84
208	Colombia	Refocosta seed stand	17	1.71 ± 0.85
101	Colombia	Refocosta seed stand	23	1.78 ± 0.85
1106	Costa Rica	DeGuate-Tailandia	24	1.79 ± 0.72
510	Tanzania	East Africa Longuza seed stand	22	1.82 ± 0.80
302	Tanzania	East Africa Longuza Progeny Trial	22	1.82 ± 0.91
909	Indonesia	Sumalindo	14	1.86 ± 0.95
213	Colombia	Refocosta seed stand	24	1.88 ± 1.03
303	Tanzania	East Africa Longuza Progeny Trial	19	1.89 ± 0.88
1109	Costa Rica	DeGuate-Tailandia	20	1.90 ± 0.85
601	Tanzania	East Africa Mtibwa	12	1.92 ± 0.90
1605	Thailand	CSIRO Thailand	24	1.92 ± 0.78
206	Colombia	Refocosta seed stand	14	1.93 ± 0.83
304	Tanzania	East Africa Longuza Progeny Trial	25	1.96 ± 0.98
301	Tanzania	East Africa Longuza Progeny Trial	18	2.00 ± 0.91
401	Tanzania	East Africa Longuza Provenance Trial	22	2.00 ± 0.82
602	Tanzania	East Africa Mtibwa	22	2.00 ± 0.69
702	Tanzania	East Africa Kihuhwi seed stand	23	2.00 ± 0.80
701	Tanzania	East Africa Kihuhwi seed stand	24	2.04 ± 0.81
1110	Costa Rica	DeGuate-Tailandia	20	2.05 ± 0.89
1709	Thailand	CSIRO Laos	15	2.07 ± 0.88
2001	Venezuela	SKCV Bulk	22	2.09 ± 0.81
1901	Mozambique	Chikweti Niasa-Lichinga	9	2.11 ± 0.60
1904	Mozambique	Chikweti Niasa-Lichinga	8	2.13 ± 0.64
402	Tanzania	East Africa Longuza Provenance Trial	23	2.13 ± 0.97
503	Tanzania	East Africa Longuza Provenance Trial	12	2.17 ± 0.94
903	Indonesia	Sumalindo	22	2.18 ± 0.80
905	Indonesia	Sumalindo	15	2.20 ± 0.77
1706	Thailand	CSIRO Laos	9	2.22 ± 0.97
1705	Thailand	CSIRO Laos	19	2.26 ± 0.87
1707	Thailand	CSIRO Laos	15	2.27 ± 1.03

Continued

1708	Thailand	CSIRO Laos	23	2.30 ± 0.70
1710	Thailand	CSIRO Laos	12	2.33 ± 0.65
1711	Thailand	CSIRO Laos	8	2.50 ± 0.93
202	Colombia	Refocosta seed stand	24	2.54 ± 0.59
901	Indonesia	Sumalindo	7	2.57 ± 0.98

CSIRO = Commonwealth scientific and industrial research organisation of the Australian government; N = Number of trees; SD = Standard deviation.

3.2. Wood Basic Density

Basic density showed a provenance effect that approached, but did not clearly reach, conventional statistical significance ($F(11,238) = 1.79$, $p < 0.056$; **Table 5**). A Tukey-Kramer-adjusted pairwise comparison identified one significant difference: East Africa Longuza Progeny Trial ($0.545 \pm 0.071 \text{ g cm}^{-3}$) had significantly higher basic density than CSIRO Thailand ($0.469 \pm 0.053 \text{ g cm}^{-3}$; Adjusted $p < 0.015$). No other pairwise comparison among the remaining 65 provenance pairs was significant (**Table 9**). The family(provenance) variance component was estimated at the boundary ($\sim 0\%$), indicating that most of the variation not attributable to block (7.0%) occurred among individual trees (93.0%) rather than between families within provenance (**Table 7**). The average basic density of the wood across all provenances was $0.517 \pm 0.059 \text{ g cm}^{-3}$.

Table 9. Basic density (g cm^{-3}) by provenance at 11 years old within study site.

Provenance code	Provenance name	N cores	BD (g cm^{-3})
3	East Africa Longuza Progeny Trial	30	0.545 ± 0.071^a
5	East Africa Longuza seed stand	8	0.536 ± 0.042^{ab}
4	East Africa Longuza Provenance Trial	35	0.533 ± 0.073^{ab}
7	East Africa Kihuhwi seed stand	16	0.532 ± 0.064^{ab}
2	Refocosta seed stand	38	0.526 ± 0.079^{ab}
12	DeGuate-Tailandia	28	0.522 ± 0.065^{ab}
19	Chikweti Niasa-Lichinga	6	0.521 ± 0.050^{ab}
9	Sumalindo	21	0.511 ± 0.037^{ab}
6	East Africa Mtibwa	18	0.508 ± 0.043^{ab}
98	SKCV Bulk	8	0.507 ± 0.069^{ab}
17	CSIRO Laos	35	0.505 ± 0.062^{ab}
16	CSIRO Thailand	13	0.469 ± 0.053^b

Means with different letters differ significantly (Tukey-Kramer adjusted $p < 0.05$). Only Longuza Progeny Trial-CSIRO Thailand pair differs significantly (Adjusted $p < 0.0153$); all other pairs are non-significant; hence most provenances share the “ab” designation.

4. Discussion

4.1. Stem Straightness

The observed straightness of CSIRO Thailand Teak provenance in this study agrees with other studies. Verhaegen et al. (2010) and Palanisamy et al. (2009) reported that Teak provenances from Thailand (CSIRO Thailand) tend to show slightly slower growth rates compared to other provenances. However, they compensate for this by producing trees characterized by excellent persistence, including a clear bole and demonstrating favourable stem form. In contrast as per the findings of this study, Palanisamy et al. (2009) and Kaosa-ard (1992) showed that Teak provenances originating from Indonesia (Sumalindo), show impressive survival rates and good health, coupled with rapid growth. However, these Indonesian provenances showed suboptimal stem form characteristics, which may be considered a limitation in certain contexts.

Additionally, Persson (1971, as cited in Pedersen et al., 2007) identified Tanzanian land races, particularly East Africa Mtibwa, as having superior stem straightness.. These findings correspond with the descriptive pattern observed in this study, as East Africa Mtibwa provenance had the numerically lowest (best) mean score and CSIRO Laos the highest (worst), as mean score 1 was for the best and 4 worst.

Wide provenance variations in Teak provenances have also been shown in other studies. Pedersen et al. (2007) and Rao et al. (2001), for example, examined the stem straightness of Teak trees from various provenances in India. According to the study, stem straightness varied widely across provenances with some having significantly straighter stems than others. Similarly, Adu-Bredu et al. (2019) assessed the stem straightness of Teak trees from various provenances in Ghana including Indonesian landraces. The researchers identified significant differences in stem straightness amongst provenances. Depending on factors such as soil conditions, climate, genetics, or geographical sources of Teak trees, may show variation in stem straightness (Bhat & Priya, 2004).

In this study, whatever differences exist among provenances in stem straightness at Longuza are small relative to tree to tree variation within families, and should not be over interpreted as evidence of strong genetic control at the provenance level in this trial. This does not mean the descriptive pattern reported above (East Africa Mtibwa, CSIRO Thailand, and East Africa Longuza seed stand scoring best) is uninformative it is directionally consistent with earlier work at this same site (Pedersen et al., 2007) but it should be presented as a descriptive tendency rather than a statistically confirmed provenance effect.

4.2. Basic Density

Wood basic density values obtained from this study on Teak trees range from 0.47 ± 0.053 to 0.55 ± 0.071 g cm⁻³, with an average of 0.517 ± 0.059 g cm⁻³, which is consistent with findings from multiple studies. For instance, Wanneng et al. (2014) found that the basic density of 10-year-old Teak planted in Laos and Solomon Islands

was 0.53 g cm^{-3} and 0.54 g cm^{-3} . Similarly, Blanco-Flórez et al. (2014) assessed Teak wood samples from different regions in Brazil, reporting basic density values with an average of 0.53 g cm^{-3} . Furthermore, Zahabu et al. (2015) analyzed Teak wood basic density in Longuza Tanzania, revealed an average range of 0.45 to 0.48 g cm^{-3} .

The mixed model detected a provenance effect on basic density approaching significance overall ($p < 0.056$), together with a significant pairwise difference between East Africa Longuza Progeny Trial and CSIRO Thailand (Adjusted $p < 0.015$). This is broadly consistent with Verhaegen et al. (2010) and Palanisamy et al. (2009), who noted distinct growth and wood property trade offs in Thailand sourced material. Given the modest replication for some provenances in this trial (as few as 6 - 8 cores for provenances 19, 5, and 98; Table 4), this result should be considered suggestive rather than conclusive, and would benefit from confirmation with a larger, more balanced sample.

The largely modest differences in basic density among Teak provenances observed here may be attributed to multiple factors. One possible reason is that the genetic variability between different provenances might not be substantial enough to cause notable variations in basic density (Nocetti et al., 2011). Furthermore, similarities in site climatic conditions, soil compositions and management practices across different provenances may contribute to this outcome, with the residual (tree-to-tree) variance component consistently dominating over both block and family(provenance) variance in this study (Bhat & Priya, 2004).

A further limitation concerns how the density sample was drawn. Because the single tree cored per plot was deliberately selected for being free of observable defects, the basic density values reported here characterise the better formed sub-population of each provenance rather than a random sample of the full stand. Provenance wide density claims, including the comparison between East Africa Longuza Progeny Trial and CSIRO Thailand reported above, should therefore be read with this selection criterion in mind, and confirmed where possible with density sampling that is not conditioned on stem form.

5. Conclusion

The study found no statistically significant variation in stem straightness among the 12 Teak provenances. Wood basic density showed a marginal overall provenance effect, with East Africa Longuza Progeny Trial significantly denser than CSIRO Thailand, though no other pairwise difference was significant. These results suggest that, at 11 years of age at Longuza, tree to tree variation within families dominates over provenance level differences for both traits, and that management or breeding decisions based on stem straightness or basic density at the provenance level should be made cautiously given the limited statistical evidence for consistent provenance differences at this stage.

6. Recommendations

Given the absence of statistically significant provenance level differences in stem

straightness, and only a single significant pairwise difference in basic density (East Africa Longuza Progeny Trial vs CSIRO Thailand), we recommend caution in selecting provenances on the basis of this trial alone. Provenances with numerically favourable stem form scores (East Africa Mtibwa, CSIRO Thailand, East Africa Longuza seed stand) and East Africa Longuza Progeny Trial for basic density remain reasonable candidates worth continued monitoring, but the statistical evidence at 11 years does not yet support strong selection recommendations at the provenance level. Re-assessment at a later age, with attention to balancing replication across provenances (some of which had as few as 6 cores in this trial), is recommended before firm breeding or deployment decisions are made.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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