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Provenance-based variation in fruit characters of teak (*Tectona grandis* L.F.)

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Abstract
The study investigates provenance-based variation in fruit characters of teak (*Tectona grandis* L. f.) collected from eleven provenances across the Western Ghats of Kerala and Karnataka. Significant variability was observed among provenances for fruit traits, including fruit length, width, thickness, number of locules per fruit and number of seeds per fruit. Fruit length ranged from 11.8 mm (Naragakkanam) to 14.5 mm (Kokilbana), while fruit width and thickness varied between 12.6 to 16.3 mm and 11.3 to 13.7 mm, respectively. The highest number of locules per fruit (3.8) was recorded in Nayarupara and the highest number of seeds per fruit (2.8) in Madanaru. The number of locules per fruit exhibited the highest genotypic (34.0%) and phenotypic (31.44%) coefficients of variation, high heritability (70.48%) and the greatest genetic gain (45.43%), indicating strong additive genetic control. Significant positive correlations were recorded among fruit length, width and thickness (r = 0.88-0.89), while the number of seeds per fruit was positively associated with locule number (r = 0.68). Provenances such as Kokilbana, Nayarupara and Madanaru demonstrated superior performance for different fruit traits, suggesting their potential as promising seed sources. The observed genetic diversity among provenances highlights ample scope for selection and improvement in teak breeding programs.

Keywords: *Tectona grandis*, provenance, fruit traits, genetic variability, correlation

Introduction
Teak (*Tectona grandis*) is one of the world's top timber species, renowned for its products and holds great potential as a plantation species. Teak in India displays significant variation across different geographic regions and provenances, particularly in terms of wood figure and strength [1]. Teak trees display variations even within smaller areas, depending on where they are located. Understanding the full range of variation in the species can help in identifying the population's that produce the best quality trees. This knowledge is also important for selecting the ideal geographic sources for seeds or planting material [2]. Investigating the variability in seed characteristics and germination behaviour of a species aids in selecting suitable seed lots for planting programs[3]. Despite centuries of heavy and often harmful exploitation, natural teak forests continue to offer valuable genetic resources. However, persistent challenges like deforestation, logging, deliberate burning and grazing are escalating, putting these natural teak populations at greater risk. This highlights the need for comprehensive data from existing field trials that compare various teak provenances, to improve the selection of seed sources for Seed Orchards for plantations and breeding programs.

Materials and Method
The experimental material consisted of fruits collected from eleven provenances of teak, representing diverse ecological zones of the Western Ghat region of Kerala and Karnataka (Table 1). Plantations aged between 20 and 30 years were selected from each provenance and from each locality, fruits were collected from 10 randomly selected trees and the fruits were bulked. Morphological characters related to the fruits were noted down. From each provenance three replicates of one kilogram each were manually drawn from the seed samples.
To evaluate fruit characteristics, a total of ten fruits were randomly selected from each provenance.

Each fruit was measured individually for its length, width and thickness using digital callipers and expressed in millimetres to ensure accuracy. For each provenance, mature fruits were dissected to assess internal seed characteristics. The number of locules per fruit was counted and the number of filled seeds present within each fruit was recorded. This data was used to evaluate seed development traits and to analyse variation among provenances. These data were subjected to statistical analysis as suggested by Gomez and Gomez [4]. The analysis of variance, test of significance of variance components and broad sense heritability are computed as suggested by Panse and Sukhatme [5].

Results and Discussions

Phenotypic variation for fruit characters among provenances

Teak from different provenances have showed significant variations for various fruit characters (Table 2). The fruit length varied from 14.5 mm to 11.8 mm in different provenances. Significant variation was observed among the eleven teak provenances with respect to fruit length. The fruit length was highest in Kokilbana (14.5 mm) followed by Ayyappancoil (13.8 mm) and lowest was in Naragakkanam (11.8 mm). The fruit width ranged from 16.3 mm to 12.6 mm. The provenance Kokilbana showed highest seed width of 16.3 mm, followed by Nayarupara (15.4 mm) and lowest was observed in Madanaru (12.6 mm). Highest fruit thickness was recorded in Kokilbana (13.7 mm), followed by Ayyappancoil (13.5 mm) and lowest was in Madanaru (11.3 mm).

The average number of locules in pod ranged from 3.8 mm to 1.5 mm. Highest number of locules was found in Nayarupara (3.8 mm) followed by Madanaru (3.3 mm) and lowest was in Cheruthoni (1.5 mm). The coefficient of variation for this trait was high (17%), which indicated high variability, that can be attributed to genetic diversity and fruit developmental differences. The number of seeds per fruit varied from 2.8 mm to 1.5 mm. It was highest in Madanaru (2.8 mm) followed by Dandeli (2.4 mm) and lowest was in Ayyappancoil and Naragakkanam (1.5 mm).

Assessment of genetic variability and associated parameters

Among the fruit traits, number of locules per fruit exhibited the highest genotypic variance (0.705), while fruit width recorded the highest phenotypic variance (1.388). The phenotypic coefficient of variation (PCV) ranged from 31.44 percent (Number of locules per fruit) to 7.11 percent (Fruit Thickness) while the genotypic coefficient of variation (GCV) ranged from 34.0 percent (Number of locules per fruit) to 5.75 percent (Fruit Width). High heritability in the broad sense was observed for number of locules per fruit, followed by fruit width, suggesting that these traits are largely under genetic control and hence selection based on phenotype would be effective (Table 3). The highest genetic gain among fruit traits was also recorded for number of locules per fruit (45.43%).

Association between characters

Among fruit traits, strong positive correlations were observed between fruit length and fruit width (0.879), as well as fruit thickness (0.894), indicating that these size-related traits improve together and may be selected jointly (Table 4). Number of seeds per fruit and number of locules per fruit showed a significant positive correlation (0.678), indicating a potential linked inheritance. Overall, the genotypic correlation matrix reveals that traits such as fruit dimensions exhibit positive and genetically linked relationships, offering useful targets for simultaneous selection in teak improvement programs.

The present study revealed significant variability among teak provenances in all examined fruit traits, including fruit length, width, thickness, number of locules and number of seeds per fruit suggesting the presence of substantial genetic diversity for these traits. The highest values for fruit length (14.5 mm), width (16.3 mm) and thickness (13.7 mm) were observed in the Kokilbana provenance indicating superior fruit size. Wide variability was observed in the average number of locules (3.8 to 1.5) and number of seeds per fruit (2.8 to 1.5) with Nayarupara and Madanaru performed well in these traits, respectively. Even though the Madanaru provenance recorded the lowest values for fruit width and thickness, it exhibited a higher number of locules and seeds per fruit, indicating that fruit size does not necessarily influence locule number or seed filling. This finding contrasts with the study by Jijeesh and Sudhakara [6], who reported that the number of seeds increased with increasing fruit size. Bhol *et al*. [7] also reported significant variation in fruit length, width and number of seeds per fruit.

The variation in seed traits across provenances can be attributed to differences in rainfall pattern. This is supported by the findings of Dhaka and Jha [8], who reported a significant positive correlation between annual rainfall and all drupe morphometric traits, while longitude and annual temperature showed no significant association. Similar observations were reported by Surendra *et al*. [9], attributing the variations to the species ability to grow across diverse climatic conditions, soil types and altitudinal ranges. Dhaka and Jha [10] reported that drupe traits such as drupe length and width were highly influenced by the location from the fruit collected also highlighted the role of locule structure in determining seed development efficiency. Considerable variation in teak drupe size among different populations was observed which can be attributed to genetic factors and environmental influences. These observations are consistent with Sivakumar *et al*. [11] and Jose and Indira [12], who reported similar ranges and suggested that locule number often positively influences seed set and filling.

Among fruit traits, the number of locules per fruit showed the highest GCV (34%) and PCV (31.44%), coupled with high heritability (70.48%) and the highest genetic gain (45.43%). This suggests that this trait is largely governed by additive gene action and can be effectively improved through phenotypic selection. Fruit width, despite having the highest phenotypic variance, showed relatively moderate GCV (5.75%) and high heritability (67.39%), suggesting that environmental influence is comparatively less and the trait can also respond positively to selection. These findings align with those of Dhaka and Jha [8], who also reported similarly high heritability for seed germination traits in teak.

Among the fruit traits, strong positive correlations were observed among fruit length, width and thickness, highlighting their potential for joint selection in improvement programs. Drupe length showed strong positive correlation with drupe width (r = 0.88). This is in support of the study of Dhaka *et al*. [13] where they obtained strong correlation between drupe length and drupe width (r = 0.907). Number of seeds per fruit and number of locules per fruit also showed significant positive correlation (r = 0.678), indicating that reproductive structures may be under linked genetic control. Correlation studies on number of seeds per fruit and size of the fruit showed that the size of the fruit was negatively correlated with number of seeds per fruit. This was supported by the study of Sivakumar *et al*. [11] which also revealed negative correlation between size of the drupe and percentage of two and three seeded drupes.

Table 1: Details of *Tectona grandis* provenances

Provenances	Fruit Length (mm)	Fruit Width (mm)	Fruit Thickness (mm)	Number of locules fruit^{-1}	Number of seeds fruit^{-1}
Nayarupara	13.3	15.4	13.1	3.8	2.4
Cheruthoni	12.7	14.8	12.6	1.5	2
Ayyappancoil	13.8	14.8	13.5	2.1	1.5
Kattappana	12.8	14.1	12.1	3	2
Kumaly	12.3	13.9	11.9	1.7	1.7
Naragakkanam	11.8	13.7	11.9	2.2	1.5
Thodupuzha	13.1	14.7	12.5	2	2
Hulgod	12.1	13.2	12.3	2.3	2
Madanaru	12.1	12.6	11.3	3.3	2.8
Dandeli	11.9	13.7	12.1	2.8	2.4
Kokilbana	14.5	16.3	13.7	2.4	2.2
Gmean	12.76	14.28	12.47	2.47	2.04
C.V.	4.68	4.71	4.94	17.07	16.85
Sem±	0.49	0.55	0.5	0.34	0.28
C.D. (0.05)	1.02	1.15	1.05	0.72	0.59

Table 2: Variation in fruit characters among different teak provenances

Sl. No.	Location	Forest Range	Forest Division
1	Nayarupara	Nagarampara	Kottayam
2	Cheruthony	Nagarampara	Kottayam
3	Ayyappancoil	Ayyappancoil	Kottayam
4	Kattappana	Ayyappancoil	Kottayam
5	Kumaly	Kumaly	Kottayam
6	Naragakkanam	Nagarampara	Kottayam
7	Thodupuzha	Thodupuzha	Kothamangalam
8	Hulgod	Kirwathi	Yellapur
9	Madanaru	Kirwathi	Yellapur
10	Dandeli	Dandeli	Haliyal
11	Kogilbana	Dandeli	Haliyal

Table 3: Estimation of Genetic Variability, Heritability and Genetic Gain for Fruit traits

Traits	Mean	Genotypic variance	Phenotypic variance	PCV	GCV	Heritability broad sense	GA	Genetic gain (%)
Fruit Length (mm)	12.76	0.624	0.948	7.63	6.19	0.623	1.243	9.741
Fruit Width (mm)	14.28	0.674	1.388	8.25	5.75	0.6739	1.628	11.401
Fruit Thickness	12.47	0.518	0.786	7.11	5.77	0.5178	0.941	7.546
Number of locules fruit $^{-1}$	2.47	0.705	0.603	31.44	34	0.7048	1.122	45.425
Number of seeds fruit $^{-1}$	2.04	0.473	0.224	23.2	33.7	0.4732	0.459	22.5

Table 4: Genotypic correlation coefficients among fruit traits in teak

Characters	Fruit Length (mm)	Fruit Width (mm)	Fruit Thickness (mm)	Number of locules fruit^{-1}	Number of seeds fruit^{-1}
Fruit Length (mm)	1	0.88	0.89	0.004	-0.06
Fruit Width (mm)	0.879	1	0.89	-0.08	-0.14
Fruit Thickness (mm)	0.89	0.89	1	-0.09	-0.22
Number of locules fruit^{-1}	0.004	-0.08	-0.08	1	0.68
Number of seeds fruit^{-1}	-0.06	-0.14	-0.22	0.68	1

Conclusion

Significant provenance-based variation was observed in fruit traits of teak (*Tectona grandis* L.f.) across the Western Ghats, indicating substantial genetic diversity. The number of locules per fruit showed the highest GCV, PCV, heritability and genetic gain, suggesting strong additive gene effects and good scope for selection. Positive correlations among fruit characters shows joint improvement through selection. Provenances such as Kokilbana, Nayarupara and Madanaru exhibited superior performance for key traits and may serve as promising sources for genetic improvement.

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