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Characterization of Drupe Traits in Sixty-Six Teak Candidate Plus Trees (CPTs) in Gujarat Forests of India for Enhanced Seed Collection and Fruit Production

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

The most valuable timber of the world *i.e.*, teak was recognized as king of wood due to its wood quality such as durability, physical and aesthetic wood property for multiple uses. It is distributed throughout India and Southeast Asia and known for center of teak genetic diversity. It has a high demand in international market and national market due to multifarious uses. However, the natural population of Teak is decreasing in India due to anthropogenic activities, deforestation, climate change and other environmental factors. In addition, the poor seed yield per tree and extremely low seed germination rates are significant problems for the teak plantation industry and production of quality seed. Nevertheless, there are huge gap between demand and supply of industrial timber in India. This can be fulfilled by the teak plantation within agroforestry systems and degraded forest lands. Gujarat forest has natural teak populations which falls in the conjunction point of Western Ghats of India. Hence, sixty-six CPTs of teak were screened out for quality seed collection and reproduction from natural teak populations. Fruits of teak were collected from various CPTs with wide range of geographic locations in Gujarat forests of India. The drupe and stone morphometric traits were studied to capture the phenotypic and genotypic variations; to select better traits on the basis of repeatability coefficient; and to look geographic location effect on various fruit characters and inter-character correlations for quality seed collection and fruit production. Present result showed significant differences ($p \leq 0.0001$) in all the studied fruit traits among 66 CPTs of *Tectona grandis.* Drupe were lengthiest in GJNBD 0467 (12.36 mm), broadest in the GJNBD 0467 (14.75 mm) and heaviest in the GJAH 1056 (0.73 g) CPT, whereas smallest in GJNBD 1122 (8.3 mm), narrowest in GJNBD 1122 (9.91 mm) and lightest in GJNBD 1122 (0.32 g) CPT. Stone were longest in GJNBD 0467 (8.71 mm), thickest in GJAH 1056 (10.01 mm) and heaviest in GJAH 1056 (0.51 g) CPT, while shortest in GJNBD 1122 (6.06 mm), thinnest stone in GJNBD 1122 (7.56 mm) and lightest in GJNBD 0772 (0.22 g) CPT. Overall, GJNBD 0467, GJAH 1056, GJNBD 0950, GJAH 0844 and GJNBD 0470 CPTs were superior for studied traits as compared to others. CPT repeatability coefficient was higher for drupe characters as compared to stone parameters, where selection can be made for drupe length for future tree improvement programme. The genetic improvement via CPT selection is better option for maintaining genetic diversity of Teak, its conservation and management. Latitude showed strong negative correlation with drupe length, stone length and drupe mass. Longitude was negatively correlated with stone length and width. Thus, the geographical parameter has an impact on the seed formation, evolution and plant fitness. The strong correlations were found among seed morphometric characters which influenced to seed development and creating fitness interaction with continuous changing environment.

Keywords: Teak fruit; king of timber; CPTs selection; repeatability coefficient; trait associations; seed evolution; teak populations.

1. INTRODUCTION

Teak is commonly known as Sagwan, Sagaun, Sag, Sagun in India. The scientific name of Sagwan is *Tectona grandis* Linn. f. (family: Lamiaceae) which is one of the world's most valuable timber, regards as king of timber or king of wood worldwide due to its wood quality such as durability, physical and aesthetic wood property (Dhaka and, 2018). Its wood is extensively used in India to make boats, railways sleepers, veneers, indoor and outdoor furniture, columns and beams in old type houses which is resistant to termite and insect attacks (Tewari, 1992). Teak is a deciduous diploid tree species with 2n = 36 chromosomes (Hedegart and Eigaard, 1965). up to 40 m height. It is indigenous to India and Southeast Asia; distributed in the states of Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Telangana, Maharashtra, Gujarat, Chhattisgarh, Madhya Pradesh, Rajasthan, Uttar Pradesh, Manipur, Orissa *etc.* (Tewari, 1992). Gujarat have natural teak forest in Dangs, Valsad, Navsari, Tapi, Vadodara, Panchmahal, Dahod, Sabarkantha and Junagarh districts (Gujarat Forest Statistics, 2012). The natural population of Teak is considerably decreased in extent as well as in density, quality and quantity in India due to anthropogenic activities, climate change and other environmental factors (Fofana et al., 2009) Most of the teak plantations established from SPAs (seed production areas) and SOs (seed orchards) in India are under threat conditions due to narrow genetic base (Balakrishnan et al., 2023). Therefore, there is need for Teak tree improvement programme and its conservation in natural teak growing areas by collecting seeds of teak from a wide range of natural population or from CPTs (Candidate Plus Trees).

Nevertheless, the gap between demand and supply of industrial timber was 20 million m^3 in 1997 and is projected to be around 110 million m^3 by 2090 in India (National Research Center for Agro-Forestry, 2007). A study forecasts a high jump in demand for roundwood equivalent volume in India of approximately 70% in the next decade, from 57.19 million m^3 in 2020 to 97.81 million m^3 in 2030. Imports of teak roundwood have also been doubled from 0.5 million m^3 in 2009 to more than a million m^3 in 2019 (Kant and Nautiyal, 2021). Each year, a lot of money (more than thousand crore rupees) is going to waste to import raw material for meet out the demand of forest or wood-based industries in India. This can be fulfilled by good quality teak plantation within agroforestry systems and degraded forest areas, which processed for the extensive establishment of plantations within and outside its native range (Pandey and Brown, 2000). But still, the poor seed yield per tree and extremely low seed germination rates are significant problems for the teak plantation industry and production of quality teak seed (Kaosa-ard, 1981). Seed related traits *viz.*, seed mass, seed size, fruit weight, fruit length and seed germination are central components of any plant life histories (Thompson, 1987). It may highly influence on reproduction system and nursery production and seedling establishment in field.

Thus, seed size, germination, seed dormancy and seed dispersal has long been regarded as significant impact on reproductive biology of plants, fruit setting and creating fitness interaction with continuous changing environment (Grime et al., 1988). In addition, there are many other factors such as rainfall, temperature, latitude, longitude, altitude and genetic plasticity which influence on the evolution of seed size and seed morphology (Dhaka and Jha, 2018), (Venable and Brown,1988). Genetic variation among seed related traits has been also documented for economically useful tropical plantation tree species such as *Gmelina arborea* (Lauridsen, 2004),(Hodge and Dvorak, 2004). *Cordia Africana* (Loha et al., 2006), (Loha et al., 2009). *Faidherbia* albida Ibrahim, 1997, *Khaya senegalensis* (Ky-Dembele et al., 2014), *Tectona grandis* (Jayasankar and Babu, 1999), (Sivakumar et al., 2002). Teak is an outcrossing tree species with prolonged life span (rotation period 100-200 years) which is subject to local environment and adaptation, and genetic variations (Kollert and Kleine Kleine, 2017). Therefore, keeping all the points in mind, the present study has been taken with the specific objectives: (1) to determine variation of morphological drupe (seed) traits of CPTs in Gujarat Forest, (2) to select better traits on the basis of repeatability coefficient, (3) to look geographic location effect on various fruit characters and inter-character correlations for quality teak seed collection and fruit production.

2. MATERIALS AND METHODS

2.1 Seed Collection and Data Measurements

The present research was conducted at College of Forestry, Navsari Agriculture University, Navsari to know the variability in drupe and stone traits of teak CPTs from Gujarat Forest. Candidate Plus Trees (CPTs) was selected by Gujarat Forest Department during 2003 in different natural teak growing forests in Gujarat state as per suggested by Zobel and Talbert (1984). Fruit/ seed collection was carried out from various geographic locations of 66 CPTs (Table 1). The Latitude and Longitude of each CPT was recorded with the help of GPS. One hundred fruits of each CPT in four lots/replications (100 fruits/ lot) were measured for analysis of the drupe attributes. Drupe and stone traits *viz.*, length (mm), width (mm) and mass (gm) were recorded for all the 66 CPTs and mean was computed. Drupe length (mm) and width (mm) was measured using digital caliper. Drupe mass (g) was evaluated using electronic weighing balance. The mesocarp was removed manually by rubbing drupes on 20 Grit Sandpaper Sheet and, stone length (mm) and width (mm) were measured for individual stone and mean was computed.

Table 1. Information about geographic location of different CPTs of *Tectona grandis* in Gujarat Forest

Sr. No.	CPTs	Latitude (N)			Longitude (E)		
1	GJAH 0739	20°	46'	31.1"	73°	30'	36.4"
2	GJAH 0793	20°	46'	32.0"	73°	30'	36.7"
3	GJAH 0834	20°	41'	37.3"	73°	32'	30.7"
4	GJAH 0835	20°	41'	37.7"	73°	32'	30.8"
5	GJAH 0836	20°	41'	37.2"	73°	32'	31.5"
6	GJAH 0844	20°	40'	13.4"	73°	39'	32.3"
7	GJAH 0845	20°	34'	55.7"	73°	39'	47.3"
8	GJAH 0846	20°	39'	55.0"	73°	39'	50.7"
9	GJAH 1029	20°	43'	19.9"	73°	39'	16.8"
10	GJAH 1056	20°	40'	30.7"	73°	30'	38.2"
11	GJAH 1113	20°	43'	17.7"	73°	29'	38.0"
12	GJAH 1115	20°	43'	17.0"	73°	29'	29.0"
13	GJAH 1116	20°	43'	17.7"	73°	29'	99.0"
14	GJAH 1124	20°	43'	17.6"	73°	29'	09.0"
15	GJAH 1128	20°	43'	19.1"	73°	29'	08.0"
16	GJAH 1130	20°	43'	16.5"	73°	59'	10.0"
17	GJBRD 0484	22°	25'	80.6"	73°	35'	75.8"
18	GJBRD 0485	22°	25'	79.3"	73°	35'	76.1"
19	GJBRD 0493	22°	24'	27.6"	73°	38'	66.1"
20	GJBRD 0494	22°	24'	29.3"	73°	38'	67.6"
21	GJBRD 0495	22°	24'	31.3"	73°	38'	68.2"
22	GJBRD 0720	22°	23'	53.9"	73°	40'	33.0"
23	GJBRD 0796	22°	23'	13.5"	73°	40'	58.9"
24	GJBRD 0848	22°	33'	50.2"	73°	56'	53.6"
25	GJBRD 0861	22°	30'	96.1"	73°	56'	80.0"
26	GJBRD 0862	22°	30'	95.5"	73°	56'	24.8"
27	GJBRD 0864	22°	29'	17.2"	73°	53'	64.4"
28	GJBRD 0870	22°	29'	16.2"	73°	53'	62.9"
29	GJBRD 0874	22°	29'	16.2"	73°	53'	70.9"
30	GJBRD 0879	22°	30'	74.4"	73°	56'	24.8"
31	GJNBD 0467	21°	40'	42.3"	73°	47'	43.1"
32	GJNBD 0468	21°	40'	42.0"	73°	47'	44.9"
33	GJNBD 0469	21°	40'	43.3"	73°	47'	46.7"
34	GJNBD 0470	21°	40'	52.0"	73°	47'	37.6"
35	GJNBD 0721	21°	40'	47.7"	73°	47'	37.9"
36	GJNBD 0769	21°	35'	84.1"	73°	43'	64.2"
37	GJNBD 0770	21°	35'	83.0"	73°	43'	64.2"
38	GJNBD 0772	21°	35'	85.0"	73°	43'	61.8"
39	GJNBD 0773	21°	35'	84.6"	73°	43'	61.0"
40	GJNBD 0775	21°	35'	82.2"	73°	43'	71.6"
41	GJNBD 0863	21°	35'	91.4"	73°	43'	42.1"
42	GJNBD 0865	21°	35'	90.0"	73°	43'	41.5"
43	GJNBD 0950	21°	40'	60.0"	73°	47'	28.8"
44	GJNBD 0951	21°	40'	61.4"	73°	47'	30.7"
45	GJNBD 0952	21°	40'	45.4"	73°	47'	38.7"
46	GJNBD 0953	21°	40'	44.4"	73°	47'	45.5"
47	GJNBD 0954	21°	40'	42.1"	73°	47'	48.6"
48	GJNBD 0955	21°	35'	91.4"	73°	43'	99.2"
49	GJNBD 0956	21°	35'	89.2"	73°	43'	33.2"
50	GJNBD 0957	21°	35'	92.0"	73°	43'	38.2"
51	GJNBD 1117	21°	52'	63.0"	73°	30'	83.7"
52	GJNBD 1122	21°	35'	92.3"	73°	44'	60.0"
53	GJNBD 1123	21°	35'	92.3"	73°	44'	22.0"

Sr. No.	CPTs	Latitude (N)			Longitude (E)		
54	GJNBD 1127	21°	35'	89.0"	73°	44'	01.1"
55	GJPMS 1038	22°	36'	27.2"	73°	44'	25.2"
56	GJPMS 1040	22°	36'	35.9"	73°	43'	20.7"
57	GJPMS 1042	22°	36'	34.1"	73°	43'	20.9"
58	GJPMS 1048	22°	36'	29.9"	73°	43'	17.1"
59	GJPMS 1195	22°	36'	45.3"	73°	43'	15.0"
60	GJPMS 1196	22°	36'	45.1"	73°	43'	19.3"
61	GJPMS 1222	22°	36'	39.6"	73°	43'	37.7"
62	GJPMS 1225	22°	36'	41.0"	73°	43'	32.1"
63	GJPMS 1228	22°	36'	42.2"	73°	43'	25.5"
64	GJPMS 1229	22°	36'	37.6"	73°	43'	26.4"
65	GJPMS 1292	22°	36'	45.7"	73°	43'	21.2"
66	GJPMS 1294	22°	36'	46.4"	73°	43'	19.6"

2.2 Statistical Analysis

All the collected data were subjected to statistical analysis using R Statistical Software and ANOVA was constructed for studied parameters as per suggested by Gomez and Gomez (Gomez and Gomez, 1984). Repeatability coefficient was calculated (Sanou et al., 2006) because genetic factors cannot be separated from environmental influence at individual tree level which can be seen as the upper limit of relation of genetic and phenotypic variance (Falconer and Mackay, 1996). Simple correlation coefficients were worked out to know the association among various traits (Panse and Sukhatme, 1978).

$$\text{Repeatability Coefficient } (R_c) = \frac{\sigma_c^2}{\sigma_c^2 + \sigma_w^2}$$

Where, $\boldsymbol{\sigma_c^2}$ is CPT variance and $\boldsymbol{\sigma_w^2}$ is within CPT variance.

3. RESULTS AND DISCUSSION

3.1 Phenotypic Variation between CPTs

There were significant differences (p≤ 0.0001) recorded in all the fruit characteristics among 66 CPTs of *T. grandis* (Table 2).

The drupes were lengthiest in GJNBD 0467 (12.36 ±0.51 mm) followed by GJAH 1056 (12.23 ±0.47 mm), GJNBD 0950 (12.08 ±0.28 mm), GJAH 1116 (11.76 ±0.50 mm), GJAH 0846 (11.71±0.36 mm) and smallest in GJNBD 1122 (8.3 ±0.25 mm) CPT of teak (Table 3). The drupes were broadest in the GJNBD 0467 (14.75 ±0.48 mm) followed by GJNBD 0470 (14.68 ±0.54 mm), GJNBD 0950 (14.56 ±0.47 mm), GJPMS 1229 (14.44 ±0.82 mm), GJAH 1056 (14.3 ±0.58 mm) and narrowest in GJNBD 1122 (9.91 ±0.43 mm) CPT of teak. The drupe mass was heaviest in the GJAH 1056 (0.73 ±0.09 g) CPT followed by (0.68±0.08 g) in GJNBD 0950, GJNBD 0470 and GJNBD 0467 CPT, whereas, the lightest drupe mass was observed in GJNBD 1122 (0.32 ±0.04 g) CPT of teak. Longest stone was observed in GJNBD 0467 (8.71 ±0.25 mm), followed by GJAH 1056 (8.61 ±0.53 mm), GJAH 0844 (8.39 ±0.43), whereas shortest in GJNBD 1122 (6.06 ±0.20 mm) CPT of teak. The thickest stone was recorded in GJAH 1056 (10.01 ±0.57 mm) followed by GJNBD 0467 (9.97 ±0.40 mm), GJAH 0844 (9.80 ±0.54 mm), GJAH 0793 (9.70 ±0.54 mm) and thinnest stone in GJNBD 1122 (7.56 ±0.22 mm) CPT of teak. The heaviest stone mass was observed in GJAH 1056 (0.51 ±0.09 g) followed by GJNBD 0467 (0.49 ±0.06 g), GJAH 0844 (0.48 ±0.07 g) and lightest stone mass observed in GJNBD 0772 (0.22 ±0.03 g) CPT of teak (Table 3). Overall, GJNBD 0467, GJAH 1056, GJNBD 0950, GJAH0844 and GJNBD 0470 Teak CPTs were performed better than all others. Variation in teak drupe traits of different seed sources was studied by Jayasankar et al. (1999) in seven provenances (Jayasankar et al., 1999). Sivakumar et al. (2002) was observed variation in different physical drupe traits such as drupe diameter, drupe weight, shell weight, mesocarp weight among 30 seed sources from three countries (Sivakumar et al., 2002). Jose and Indira (2010) also analyzed variability of seed related characters in teak from Western Ghat region among 10 provenances (Jose and Indira, 2010) They found that the mean value of drupe diameter length, drupe diameter and 100 drupe weight were 12.3 mm, 13.6 mm and 53.01 g, respectively. Teak drupe graded into three diameter classes of 9-12, 12-15 and 15-18 mm to find out the effect of drupe size on earliness of germination, seedling growth and root growth (Jijeesh and Sudhakara, 2014). The bigger size drupe was found to be significant influence the vigour of seedlings in the initial stage of growth. Therefore, drupe collection for regeneration is directly related to drupe size and drupe mass. There are several other tropical tree species where such type seed related variation found to be useful for tree improvement *viz.*, *Gmelina arborea* (Lauridsen, 2004),(Hodge and Dvorak, 2004), *Faidherbia* albida (Ibrahim et al., 1997), *Cordia Africana* (Loha et al., 2016), (Loha et al.,2009), *Khaya senegalensis* (Ky-Dembele et al., 2014), *Millettia ferruinea* (Loha et al., 2008).

3.2 Genotypic Variation and Heredity of Traits

Repeatability coefficient is the upper limit in relation of genetic and phenotypic variance. CPT repeatability coefficient was higher for drupe characters as compared to stone parameters. CPT repeatability coefficient was highest in length (0.824) followed by width (0.807) and mass (0.80) of drupe, whereas the lowest value was observed in stone length (0.739) followed by stone width (0.744) (Table 4). The patterns of variation exhibited for various traits were substantially different on the basis of coefficient variation as natural selection acting upon these traits (Ginwal et al., 2005). All the traits were having high repeatability coefficient of variation as an upper limit of heritability. It is a good indicator of selection efficiency (Sanou et al., 2006). Similarly, higher tree to tree genetic variation for fruit and seed traits has been reported in various tree species such as *Millettia ferruinea* (Lohaet al., 2008). *Cordia Africana* (Loha et al., 2006), (Loha et al., 2009). *Jatropha curcas* (Ginwal et al., 2005). Several seed producing traits such as seed production per ramet, seed producing index, a number of relative female strobili, a number of scales, and a number of ineffective scales of Chinese pine (*Pinus tabuliformis*) were reported comparatively high repeatability coefficient at 0.86, 0.87, 0.89, 0.96, and 0.91, respectively (Yuan et al., 2005). Here, drupe length is the best trait where selection can be made for further genetic improvement of CPT selection and also better option for maintaining genetic diversity from selection.

3.3 Effect of Geographic Parameters on Fruit Evolution

Geographic variables such as latitude showed strong negative correlation with drupe length (r = -0.383, p< 0.01) and stone length (r = -0.327, p< 0.01); and also exhibited a fair negative correlation with drupe Mass (r = -0.299, p< 0.05). Longitude was negatively correlated with stone length (r = -0.285, p< 0.05) and width (r = -0.244, p< 0.05) significantly (Table 5). Seed size (length, width, depth, weight and 1000 seed weight) of natural populations of *Pinus halepensis* was negatively correlated with both geographic parameters i*.e.*, altitude and longitude (Boulli et al., 2001) Among and within perennial Australian Glycine species, a significant negative relationship emerged between seed size and latitude as well as seed size and longitude (Murray et al., 2003). Both latitude and longitude in this study showed negative correlation with some drupe and stone traits, this is supported by above research studies in tree crops. Thus, the geographical parameters had significant effect on the seed evolution and plant fitness in teak.

3.4 Association between Characters

All the drupe and stone traits showed a strong significant (p <0.01) positive correlation with each other (Table 6). Drupe length showed a strong correlation with drupe width (r=0.907) and all others. Then drupe width exhibited a strong correction with drupe mass (r=0.913) and all others. Drupe mass showed very strong association with stone mass (r=0.951). Stone length was positively correlated with stone width (r=0.92) and stone width with stone mass (r=0.937). Sivakumar et al. (2002) found that drupe diameter, drupe weight, mesocarp weight and other drupe parameters were strongly intercorrelated to each other which strongly support the present result (Sivakumar et al., 2013). Lyngdoh et al. (2013) was also exhibited positive correlation of drupe diameter with drupe weight of teak (Lyngdoh et al., 2013).A strong inter-trait correlation was reported among drupe and seed traits of teak; and these traits were also influenced on the drupe and seed germination character (Dhaka and Jha, 2017) Seed width was positively correlated with seed weight in *Millettia ferruinea* (Loha et al., 2008) Seed length, width and weight of *Cordia africana* seed were showed strongly positive correlation to each other (Loha et al., 2009) Thus, all the drupe and stone traits closely related to each other and influenced to seed formation, evolution and seed production in the natural forest of Gujarat state.

Table 2. Analysis of variance for drupe and stone traits in *Tectona grandis*

Traits	CPTs (df = 65)		
	Mean Square	**F Value**	**P > F**
Drupe Length	3.282	19.719	<.0001
Drupe Width	4.141	17.756	<.0001
Drupe Mass	0.034	14.413	<.0001
Stone Length	1.072	12.346	<.0001
Stone Width	1.110	12.668	<.0001
Stone Mass	0.014	12.910	<.0001

Table 3. Mean variation for drupe and stone traits among sixty-six CPTs of *Tectona grandis*

CPTs	Drupe Length (mm)		Drupe Width (mm)		Drupe Mass (g)		Stone Length (mm)		Stone Width (mm)		Stone Mass (g)	
GJAH 0739	10.70	±0.78	13.04	±0.86	0.62	±0.12	8.01	±0.41	9.50	±0.52	0.40	±0.08
GJAH 0793	11.42	±0.75	13.73	±0.87	0.64	±0.11	8.25	±0.41	9.70	±0.54	0.46	±0.08
GJAH 0834	10.96	±0.46	12.81	±0.61	0.49	±0.05	7.26	±0.19	8.87	±0.24	0.34	±0.03
GJAH 0835	10.83	±0.35	13.56	±0.45	0.52	±0.05	7.68	±0.18	9.02	±0.23	0.34	±0.03
GJAH 0836	9.73	±0.69	11.40	±0.64	0.44	±0.09	6.89	±0.40	8.52	±0.48	0.31	±0.07
GJAH 0844	11.08	±0.56	13.42	±0.67	0.67	±0.09	8.39	±0.43	9.80	±0.54	0.48	±0.07
GJAH 0845	11.62	±0.61	13.95	±0.82	0.67	±0.10	8.25	±0.37	9.64	±0.42	0.45	±0.07
GJAH 0846	11.71	±0.36	13.73	±0.58	0.63	±0.08	8.33	±0.36	9.59	±0.40	0.44	±0.06
GJAH 1029	10.35	±0.36	12.16	±0.68	0.51	±0.07	7.44	±0.31	9.04	±0.42	0.38	±0.06
GJAH 1056	12.23	±0.47	14.30	±0.58	0.73	±0.09	8.61	±0.53	10.01	±0.57	0.51	±0.09
GJAH 1113	9.70	±0.36	11.47	±0.36	0.40	±0.05	7.20	±0.21	8.68	±0.35	0.30	±0.05
GJAH 1115	10.18	±0.41	12.51	±0.63	0.43	±0.05	7.64	±0.25	8.87	±0.36	0.32	±0.05
GJAH 1116	11.76	±0.50	13.24	±0.62	0.62	±0.07	8.07	±0.26	9.56	±0.32	0.45	±0.06
GJAH 1124	10.74	±0.50	12.77	±0.57	0.50	±0.08	7.64	±0.29	9.33	±0.37	0.35	±0.06
GJAH 1128	10.05	±0.35	11.77	±0.49	0.48	±0.07	7.37	±0.39	8.72	±0.27	0.35	±0.05
GJAH 1130	10.97	±0.14	13.55	±0.28	0.54	±0.02	7.74	±0.16	9.00	±0.25	0.37	±0.03
GJBRD 0484	9.69	±0.25	12.29	±0.21	0.44	±0.05	7.37	±0.24	8.86	±0.25	0.32	±0.05
GJBRD 0485	9.88	±0.16	12.16	±0.21	0.48	±0.05	7.21	±0.12	8.81	±0.26	0.35	±0.04
GJBRD 0493	9.65	±0.47	11.23	±0.32	0.36	±0.04	7.01	±0.30	8.19	±0.26	0.26	±0.04
GJBRD 0494	10.23	±0.27	12.84	±0.47	0.49	±0.07	7.39	±0.23	8.99	±0.47	0.35	±0.05
GJBRD 0495	9.78	±0.32	11.79	±0.60	0.41	±0.05	7.27	±0.17	8.56	±0.17	0.30	±0.04

CPTs	Drupe Length (mm)		Drupe Width (mm)		Drupe Mass (g)		Stone Length (mm)		Stone Width (mm)		Stone Mass (g)	
GJBRD 0720	10.44	±0.39	12.23	±0.37	0.40	±0.05	7.08	±0.22	8.36	±0.28	0.27	±0.04
GJBRD 0796	10.10	±0.32	12.21	±0.42	0.45	±0.06	7.06	±0.22	8.85	±0.24	0.30	±0.05
GJBRD 0848	9.37	±0.30	12.00	±0.26	0.41	±0.04	6.88	±0.24	8.52	±0.28	0.32	±0.03
GJBRD 0861	9.59	±0.31	11.81	±0.51	0.42	±0.05	6.83	±0.16	8.71	±0.26	0.33	±0.04
GJBRD 0862	9.18	±0.41	11.74	±0.32	0.39	±0.04	7.06	±0.34	8.47	±0.24	0.32	±0.03
GJBRD 0864	9.83	±0.33	11.93	±0.39	0.43	±0.04	7.24	±0.27	8.61	±0.34	0.34	±0.04
GJBRD 0870	10.21	±0.24	12.20	±0.41	0.47	±0.03	7.00	±0.14	8.70	±0.15	0.36	±0.03
GJBRD 0874	9.68	±0.31	12.11	±0.56	0.45	±0.05	6.92	±0.24	8.81	±0.36	0.35	±0.04
GJBRD 0879	9.72	±0.34	12.21	±0.37	0.43	±0.04	6.67	±0.25	8.46	±0.26	0.32	±0.03
GJNBD 0467	12.36	±0.51	14.75	±0.48	0.68	±0.08	8.71	±0.25	9.97	±0.40	0.49	±0.06
GJNBD 0468	9.65	±0.63	11.12	±0.72	0.41	±0.08	7.40	±0.49	8.38	±0.54	0.31	±0.06
GJNBD 0469	10.24	±0.43	12.75	±0.57	0.48	±0.06	7.10	±0.33	8.63	±0.36	0.34	±0.05
GJNBD 0470	11.62	±0.42	14.68	±0.54	0.68	±0.08	7.73	±0.23	9.68	±0.28	0.44	±0.05
GJNBD 0721	10.82	±0.27	12.95	±0.36	0.50	±0.04	7.19	±0.18	8.70	±0.25	0.35	±0.03
GJNBD 0769	8.52	±0.44	10.21	±0.52	0.35	±0.05	6.28	±0.28	7.64	±0.37	0.25	±0.04
GJNBD 0770	10.66	±0.55	12.90	±0.43	0.52	±0.08	7.66	±0.30	9.00	±0.40	0.37	±0.06
GJNBD 0772	8.73	±0.40	10.17	±0.44	0.32	±0.04	6.51	±0.23	7.65	±0.33	0.22	±0.03
GJNBD 0773	8.38	±0.44	10.22	±0.69	0.33	±0.02	6.42	±0.38	7.67	±0.38	0.27	±0.07
GJNBD 0775	11.17	±0.25	13.09	±0.54	0.54	±0.06	7.67	±0.34	9.21	±0.28	0.37	±0.04
GJNBD 0863	9.85	±0.35	12.27	±0.55	0.48	±0.06	7.19	±0.26	8.45	±0.27	0.32	±0.04
GJNBD 0865	10.42	±0.32	12.65	±0.38	0.47	±0.05	7.35	±0.27	8.70	±0.32	0.35	±0.04
GJNBD 0950	12.08	±0.28	14.56	±0.47	0.68	±0.06	7.64	±0.23	9.51	±0.18	0.43	±0.04
GJNBD 0951	10.82	±0.30	13.28	±0.46	0.55	±0.06	7.98	±0.16	9.56	±0.34	0.40	±0.04
GJNBD 0952	10.20	±0.32	12.19	±0.39	0.49	±0.06	7.48	±0.44	8.94	±0.41	0.36	±0.06
GJNBD 0953	10.83	±0.34	12.65	±0.53	0.54	±0.06	7.58	±0.33	9.00	±0.30	0.37	±0.05
GJNBD 0954	10.61	±0.33	12.63	±0.47	0.50	±0.06	7.45	±0.20	8.98	±0.36	0.37	±0.04
GJNBD 0955	10.88	±0.47	12.53	±0.48	0.51	±0.08	7.26	±0.38	8.83	±0.52	0.35	±0.05
GJNBD 0956	10.34	±0.68	12.42	±0.70	0.50	±0.09	7.24	±0.36	8.67	±0.42	0.33	±0.06
GJNBD 0957	10.85	±0.47	12.78	±0.52	0.51	±0.05	7.30	±0.26	8.69	±0.35	0.36	±0.04
GJNBD 1117	10.51	±0.65	12.31	±0.83	0.51	±0.07	7.01	±0.27	9.19	±0.44	0.33	±0.06
GJNBD 1122	8.30	±0.25	9.91	±0.43	0.32	±0.04	6.06	±0.20	7.56	±0.22	0.23	±0.03
GJNBD 1123	10.38	±0.46	13.00	±0.78	0.52	±0.09	7.77	±0.51	9.05	±0.46	0.38	±0.06
GJNBD 1127	10.66	±0.39	13.30	±0.71	0.55	±0.08	7.93	±0.38	9.24	±0.50	0.41	±0.06
GJPMS 1038	8.98	±0.38	11.45	±0.57	0.45	±0.07	7.46	±0.31	8.82	±0.41	0.36	±0.06

CPTs	Drupe Length (mm)		Drupe Width (mm)		Drupe Mass (g)		Stone Length (mm)		Stone Width (mm)		Stone Mass (g)	
GJPMS 1040	9.75	±0.20	12.21	±0.36	0.50	±0.05	7.52	±0.44	8.99	±0.37	0.38	±0.05
GJPMS 1042	10.78	±0.37	12.79	±0.55	0.54	±0.06	7.82	±0.23	9.26	±0.24	0.40	±0.04
GJPMS 1048	10.15	±0.41	12.17	±0.58	0.48	±0.07	7.36	±0.24	8.69	±0.31	0.34	±0.05
GJPMS 1195	9.67	±0.26	12.70	±0.85	0.54	±0.08	7.93	±0.40	9.32	±0.44	0.42	±0.07
GJPMS 1196	10.10	±0.15	12.34	±0.53	0.49	±0.06	7.42	±0.38	8.80	±0.25	0.35	±0.05
GJPMS 1222	8.71	±0.46	11.67	±0.52	0.48	±0.05	7.14	±0.25	8.66	±0.30	0.36	±0.04
GJPMS 1225	9.94	±0.32	12.17	±0.31	0.51	±0.04	7.62	±0.35	9.22	±0.31	0.39	±0.04
GJPMS 1228	8.97	±0.60	12.65	±0.72	0.45	±0.09	6.88	±0.60	8.43	±0.56	0.30	±0.07
GJPMS 1229	11.60	±0.47	14.44	±0.82	0.67	±0.13	7.79	±0.48	9.58	±0.76	0.45	±0.09
GJPMS 1292	10.26	±0.54	12.13	±0.74	0.48	±0.08	7.60	±0.30	9.02	±0.34	0.36	±0.06
GJPMS 1294	10.49	±0.47	12.30	±0.56	0.52	±0.07	7.69	±0.41	9.25	±0.44	0.40	±0.07
Mean	**10.30**		**12.49**		**0.50**		**7.42**		**8.90**		**0.36**	
SE(m)±	**0.20**		**0.24**		**0.02**		**0.15**		**0.15**		**0.02**	
C.D.	**0.57**		**0.67**		**0.07**		**0.41**		**0.41**		**0.05**	
C.V.	**3.96**		**3.87**		**9.77**		**3.97**		**3.33**		**9.28**	

Table 4. Variance component and repeatability coefficient for drupe and stone traits in *Tectona grandis*

Traits	CPT Varinace (σ_c^2)	Within CPT Variance (σ_w^2)	Repeatability Coefficient (R_c)
Drupe Length	0.166	0.779	0.824
Drupe Width	0.233	0.977	0.807
Drupe Mass	0.002	0.008	0.800
Stone Length	0.087	0.246	0.739
Stone Width	0.088	0.256	0.744
Stone Mass	0.001	0.003	0.765

Table 5. Correlation between geographic parameter and drupe- and stone- related traits of *Tectona grandis*

Traits	Latitude	Longitude
Drupe Length	-0.383**	-0.214NS
Drupe Width	-0.218NS	-0.086NS
Drupe Mass	-0.299*	-0.204NS
Stone Length	-0.327**	-0.285*
Stone Width	-0.235NS	-0.244*
Stone Mass	-0.209NS	-0.111NS

*Note: N = 66; * = Significant, p < 0.05; ** = Highly significant, p < 0.01; NS = Non- significant*

Table 6. Correlation matrix among drupe- and stone- related traits of *Tectona grandis*

Traits	Drupe Length	Drupe Width	Drupe Mass	Stone Length	Stone Width	Stone Mass
Drupe Length	1					
Drupe Width	0.907**	1				
Drupe Mass	0.884**	0.913**	1			
Stone Length	0.808**	0.812**	0.870**	1		
Stone Width	0.847**	0.880**	0.930**	0.920**	1	
Stone Mass	0.803**	0.842**	0.951**	0.898**	0.937**	1

*Note: N = 66; * = Significant, p < 0.05; ** = Highly significant, p < 0.01*

4. CONCLUSION

The most valuable timber of the world *i.e.*, Teak was distributed throughout India, whereas Gujarat state has natural teak forests. The Valsadi Teak is famous for sheep building in ancient India. CPTs of teak were screened out in Gujarat teak forest for quality seed collection and reproduction. The drupe and stone morphometric characters were showed significant differences in all the fruit characteristics among 66 CPTs of *T. grandis.* Overall, GJNBD 0467, GJAH 1056, GJNBD 0950, GJAH 0844 and GJNBD 0470 CPTs were showed superior fruit quality than all others. CPT repeatability coefficient was revealed that selection can be made from drupe length for further genetic improvement of Teak and CPT selection. Latitude and longitude showed negative correlation with drupe traits which play a major role on the seed formation, evolution and plant fitness. The strong inter-character correlation was found among fruit traits which influenced to seed development and creating fitness interaction with continuous changing environment. This research study is very useful for improvement, conservation and management of teak genetic resources in Gujarat forests of India.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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