Development of Morphological Descriptors For Characterization of Teak (*Tectona Grandis* L. f.) Seed Sources In India

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Abstract

Teak (*Tectona grandis* L.f.) plantations in India has been intensified in the recent past yet, morphological descriptors for teak is still lacking. Hence, this study aimed to develop descriptors using morphological traits. Among 30 seed sources collected from different states of India, 24 morphological descriptors *viz.*, leaf length, leaf width, presence of petiole, petiole length, leaf shape, shape of leaf apex, shape of leaf base, leaf texture, phyllotaxy, leaf attitude, leaf margin, leaf margin undulation, leaf brightness, leaf venation, leaf main vein, leaf veins, leaf vein colour, leaf colour, leaf pubescence, young leaf colour, number of internodes, internodal length, trunk spots and trunk colour were developed based on leaf and stem characteristics. Subsequently, genetic similarity among the sources were estimated by Jaccard similarity index and cluster analysis was performed by Unweighted Pair Group Method with Arithmetic mean (UPGMA) method.

Introduction

Teak (*Tectona grandis* L.f.) has been regarded as most precious tropical timber with a worldwide reputation and also known as “King of Timber” (White, 1991). Teak, a member of the Lamiaceae family which is native to the Indian–Burmese floristic region and is naturally distributed in India, Myanmar, the Laos People’s Democratic Republic and Thailand, and naturalized in Java, Indonesia (Pandey and Brown, 2000; Verhaegen et al., 2010). The increasing worldwide demand for teak wood, and the alarming decline in the currently available resources, has resulted in an intensification of teak planting activities since the early 1970’s (Keogh, 2001). Choosing the best teak origins remains a crucial constraint to maximize the productivity, bearing in mind that timber yields and quality are prone to vary considerably depending on the site conditions (Kajar *et al.*, 2000; Keogh, 2001). Genetic diversity and genetic variation are key component of the stability of forest resources (Rajora et al., 2000). Hence it is important to evaluate the genetic diversity and genetic divergence of natural populations in native countries to facilitate conservation efforts aimed at maintaining species genetic resources.

The classification of cultivated plant genotypes is an important step in breeding programs, germplasm conservation and is essential in the process of plant protection. In order to implement the ‘*Sui Generis*’ system for plant variety protection for granting Plant Breeding Rights (PBR) to a breeder or farmer or institution, DUS testing is compulsory (PPV&FRA, 2001). A new variety shall be registered if it conforms to the criteria of Novelty, Distinctness, Uniformity and Stability (DUS) (Shobha *et al.*, 2006). In order to protect genetic resources through the existing legal framework it is essential to develop DUS traits. Under such circumstances, attempts were made to characterize and document DUS traits for Teak genetic resources deploying 30 seed sources. As of now, there is only scanty studies available on systematic documentation of morphological characteristics of Teak in India and worldwide. Thus, the aim of this study was to develop morphological descriptors to discriminate teak germplasm in plantations in order to propose morphological descriptors to support the cultivars protection process.

Materials And Methods

The present study was conducted in seven months old seed source evaluation trial established at Forest College and Research Institute, Mettupalayam (11°19' N; 76°56' E; 300 meters above MSL) during 2021. The materials for the present study consisted of 30 seed sources (Table 1) collected from selected plus trees of eleven different states *viz.*, Tamil Nadu, Tripura, Maharashtra, Odisha, Gujarat, Kerala, Karnataka, Andhra Pradesh, Madhya Pradesh, Chhattisgarh and Jharkhand. The assembled seed sources were established in the seed source evaluation trial using Randomized Block Design (RBD) with 8 plants per plot with three replications at an espacement of 4m x 4m. Data were collected on morphological (both quantitative and qualitative) characters. The type of assessment of vegetative characteristics followed as per standard method prescribed (UPOV, 1989).

- MG: Measurement by a single observation of a group of plants or parts of plants.
- VG: Visual assessment by a single observation of a group of plants or parts of plants.

Table 1
Details of evaluated teak seed source with their origin and source code

S.No.	Place	State	Assigned Number	Source Code
1.	Nellithurai	Tamil Nadu	FCRITK 01	1
2.	Nellithurai	Tamil Nadu	FCRITK 02	2
3.	Kallar	Tamil Nadu	FCRITK 03	3
4.	Oomapalayam	Tamil Nadu	FCRITK 04	4
5.	Kallar	Tamil Nadu	FCRITK 05	5
6.	Kallar RF	Tamil Nadu	FCRITK 06	6
7.	Agartala	Tripura	FCRITK 07	7
8.	Nellithurai	Tamil Nadu	FCRITK 08	8
9.	Vilamarathur	Tamil Nadu	FCRITK 09	9
10.	Salem	Tamil Nadu	FCRITK 10	10
11.	Burliyar	Tamil Nadu	FCRITK 11	11
12.	Chandrapur	Maharashtra	FCRITK 12	12
13.	Chandrapur	Maharashtra	FCRITK 13	13
14.	Chandrapur	Maharashtra	FCRITK 14	14
15.	Chandrapur	Maharashtra	FCRITK 15	15
16.	Chandrapur	Maharashtra	FCRITK 16	16
17.	Chandrapur	Maharashtra	FCRITK 17	17
18.	Tanjore	Tamil Nadu	FCRITK 18	18
19.	Rairakhol	Odisha	FCRITK 19	19
20.	Dang	Gujarat	FCRITK 20	20
21.	Nilambur	Kerala	FCRITK 21	21
22.	Parambikulam	Kerala	FCRITK 22	22
23.	Thenmala	Kerala	FCRITK 23	23
24.	Shivamogga	Karnataka	FCRITK 24	24
25.	Valsad	Gujarat	FCRITK 25	25
26.	Dandeli	Karnataka	FCRITK 26	26
27.	Khandwa	Madhya Pradesh	FCRITK 27	27

S.No.	Place	State	Assigned Number	Source Code
28.	Vizianagaram	Andra Pradesh	FCRITK 28	28
29.	Raipur	Chhattisgarh	FCRITK 29	29
30.	Ranchi	Jharkhand	FCRITK 30	30

Genetic similarity and cluster analysis

Based on the descriptors, data were transformed into a binary matrix for statistical analysis. The binary matrices of presence (1) and absence (0) were arranged according to the level of expression of the characteristics expressed by each source. After deriving the binary matrix, the genetic similarity among the sources was calculated by means of the Jaccard similarity index (SJ).

$$SJ = \frac{c}{(a + b - c)}$$

Where,

a = number of morphological characteristics occurring in source 1

b = number of morphological characteristics occurring in source 2

c = number of common morphological characteristics in the two sources.

The clustering analysis was performed by the UPGMA method (Unweighted Pair Group Method with Arithmetic mean) by means of Past 4.03 software (Hammer et al., 2001).

Results

Thirty Teak sources were characterized for DUS traits in order to protect the genetic resources through potential IPR mechanism. The teak sources were characterized for stem and leaf characteristics and are presented in Table 2 & 3. Significant variation was recorded among the teak genetic resources for the following 24 characters *viz.*, leaf length, leaf width, presence of petiole, petiole length, leaf shape, shape of leaf apex, shape of leaf base, leaf texture, phyllotaxy, leaf attitude, leaf margin, leaf margin undulation, leaf brightness, leaf venation, leaf main vein, leaf veins, leaf vein colour, leaf colour, leaf pubescence, young leaf colour, number of internodes, internodal length, trunk spots and trunk colour.

Table 2
Leaf morphological traits evaluated in teak seed sources

S.No.	Characteristics	Levels of Expression	Distribution of classes	Source code
1	Leaf Length (cm)	40–50 cm	5 (16.7%)	1, 4, 6, 18, 28
		50–60 cm	15 (50%)	2, 3, 7, 8, 9, 10, 11, 12, 19, 20, 21, 22, 23, 24, 26
		> 60 cm	10 (33.3%)	5, 13, 14, 15, 16, 17, 25, 27, 29, 30
2	Leaf width (cm)	30–40 cm	5 (16.7%)	1, 4, 6, 18, 24
		40–50 cm	17 (56.7%)	3, 5, 7, 8, 9, 10, 11, 12, 13, 17, 19, 20, 21, 22, 23, 26, 28
		50–60 cm	8 (26.6%)	2 14, 15, 16, 25, 27, 29, 30
3	Presence of Petiole	Petiolate	26 (86.7%)	2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26, 27, 28, 29
		Sessile	4 (13.3%)	1, 5, 21, 30
4	Petiole length (cm)	2–4 cm	4 (15.4%)	6, 8, 11, 26
		4–6 cm	9 (34.6%)	2, 3, 4, 7, 9, 13, 17, 22, 29
		> 6 cm	13 (50%)	10, 12, 14, 15, 16, 18, 19, 20, 23, 24, 25, 27, 28
5	Leaf Shape	Ovate	30 (100%)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
6	Shape of Leaf Apex	Acute	30 (100%)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
7	Shape of Leaf Base	Obtuse	22 (73.4%)	2, 3, 4, 7, 8, 10, 12, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26, 27, 28, 29
		Cuneate	4 (13.3%)	6, 9, 11, 13
		Attenuated	4 (13.3%)	1, 5, 21, 30
8	Leaf Texture	Glabrous	5 (16.7%)	9, 19, 21, 26, 28
		Coriaceous	13 (43.3%)	1, 2, 3, 4, 6, 7, 8, 10, 11, 18, 22, 23, 24
		Scrabber	12 (40%)	5, 12, 13, 14, 15, 16, 17, 20, 25, 27, 29, 30

S.No.	Characteristics	Levels of Expression		Distribution of classes	Source code
9	Phyllotaxy	Opposite		30 (100%)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
10	Leaf Attitude	Bending		13 (43.3%)	5, 6, 7, 9, 12, 13, 19, 20, 21, 22, 25, 29, 30
		Horizontal		17 (56.7%)	1, 2, 3, 4, 8, 10, 11, 14, 15, 16, 17, 18, 23, 24, 26, 27, 28
11	Leaf Margin	Whole		30 (100%)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
12	Leaf Margin Undulation	Low		24 (80%)	1, 2, 5, 6, 7, 9, 10, 11, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 27, 28, 29, 30
		Medium		6 (20%)	3, 4, 8, 12, 14, 25
13	Leaf Brightness	Present		12 (40%)	1, 3, 4, 6, 7, 8, 10, 18, 19, 23, 24, 28
		Absent		18 (60%)	2, 5, 9, 11, 12, 13, 14, 15, 16, 17, 20, 21, 22, 25, 26, 27, 29, 30
14	Leaf Venation	Touches the margin		30 (100%)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
15	Leaf Main Vein	Touches the margin		30 (100%)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
16	Leaf Veins	Tertiary		6 (20%)	2, 5, 7, 9, 10, 20
		Quaternary		24 (80%)	1, 3, 4, 6, 8, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
17	Leaf Vein Colour	Light yellow		2 (6.7%)	3, 6
		Yellowish green		9 (30%)	2, 5, 14, 15, 16, 17, 20, 21, 22
		Light yellowish green		19 (63.3%)	1, 4, 7, 8, 9, 10, 11, 12, 13, 18, 19, 23, 24, 25, 26, 27, 28, 29, 30
18	Leaf Colour	Adaxial	Dark green	26 (86.7%)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 14, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 28, 29, 30
			Light green	4 (13.3%)	12, 13, 15, 27
		Aboxial	Greyish green	8 (26.6%)	1, 3, 11, 16, 17, 19, 20, 26

S.No.	Characteristics	Levels of Expression		Distribution of classes	Source code
			Light greyish green	3 (10%)	2, 25, 27
			Light green	16 (53.4%)	4, 5, 6, 7, 8, 9, 10, 14, 15, 18, 21, 22, 23, 24, 28, 30
			Light yellowish green	3 (10%)	12, 13, 29
19	Leaf Pubescence	Adaxial	Absent	30 (100%)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
		Aboxial	Present	11 (36.7%)	4, 5, 12, 13, 15, 16, 17, 20, 27, 29, 30
			Absent	19 (63.3%)	1, 2, 3, 6, 7, 8, 9, 10, 11, 14, 18, 19, 21, 22, 23, 24, 25, 26, 28
20	Young Leaf Colour	Adaxial	Greyish green	3 (10%)	1, 18, 28
			Light greenish brown	10 (33.3%)	2, 4, 5, 8, 10, 11, 15, 16, 24, 27
			Dark greenish brown	4 (13.3%)	13, 22, 25, 29
			Light brown	6 (20%)	3, 6, 7, 19, 23, 26
			Dark brown	3 (10%)	12, 20, 30
			Green	2 (6.7%)	14, 17
			Purplish green	2 (6.7%)	9, 21
		Aboxial	Light greyish green	2 (6.7%)	1, 18
			Light greenish brown	13 (43.3%)	2, 4, 5, 6, 8, 10, 11, 15, 16, 22, 24, 29, 30
			Greenish brown	5 (16.7%)	3, 12, 13, 20, 27
			Light green	4 (13.3%)	14, 17, 25, 28

S.No.	Characteristics	Levels of Expression	Distribution of classes	Source code
		Light brown	4 (13.3%)	7, 19, 23, 26
		Light purplish green	2 (6.7%)	9, 21

Table 3
Stem morphological traits evaluated in teak seed sources

S.No.	Characteristics	Levels of Expression		Distribution of classes	Source code
1	No. of Internodes	4–5		12 (40%)	1, 3, 6, 7, 14, 16, 17, 22, 25, 27, 29, 30
	(Measured from 1m above the ground level)	5–6		8 (26.6%)	9, 10, 12, 15, 19, 20, 23, 26
		> 6		10 (33.3%)	2, 4, 5, 8, 11, 13, 18, 21, 24, 28
2	Internodal Length	13–16 cm		11 (36.7%)	3, 4, 6, 8, 9, 11, 12, 15,18, 21, 28
	(Measured from 1m above the ground level)	16–19 cm		10 (33.3%)	1, 2, 5, 7, 10, 19, 20, 23, 24, 26
		> 19 cm		9 (30%)	13, 14, 16, 17, 22, 25, 27, 29, 30
3	Trunk spots	Present		30 (100%)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
4	Trunk Colour	Base	Grey	30 (100%)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
			Light green	2 (6.7%)	12, 17
			Dark green	20 (66.7%)	1, 2, 3, 4, 6, 7, 8, 9, 10, 14, 18, 19, 21, 22, 23, 24, 26, 27, 28, 30
		Top	Greyish green	8 (26.6%)	5, 11, 13, 15, 16, 20, 25, 29
			Light green	6 (20%)	1, 6, 7, 17, 18, 27
			Green	17 (56.7%)	2, 3, 4, 5, 8, 9, 10, 13, 14, 19, 21, 22, 23, 24, 26, 28, 30
			Greyish green	7 (23.3%)	11, 12, 15, 16, 20, 25, 29

Leaf characterization

Leaf length: The leaf length was grouped into short (40–50 cm), medium (50–60 cm) and long (> 60 cm). Fifteen sources (50%) exhibited medium leaf length followed by ten sources (33.3%) under long category and five sources (16.7%) exhibited short leaf length.

Leaf width: Leaf width of teak sources were categorized into short (30–40 cm), medium (40–50 cm) and long (50–60 cm). 56.7% of the sources recorded medium leaf width followed by long (26.6%) and short (16.7%).

Presence of petiole: Presence of petiole (Fig. 2a) was predominantly reported in twenty six (86.7%) sources. Four sources *viz.*, FCRITK 01, FCRITK 05, FCRITK 21 and FCRITK 30 exhibited sessile leaf.

Petiole length: Leaf petiole length of teak is categorized into three *viz.*, short (2–4 cm), intermediate (4–6 cm) and wide (6–8 cm) (Fig. 2b). Thirteen sources (43.4%) exhibited wide petiole length followed by intermediate (30%) in nine sources and short in four sources (13.3%).

Leaf shape: All the teak sources predominantly exhibited ovate leaf shape.

Shape of leaf apex: All the teak sources registered acute leaf apex.

Shape of leaf base: The Base shape of teak leaf sample recorded three categories *viz.*, obtuse, cuneate and attenuated (Fig. 2c). Twenty two (73.4%) sources exhibited obtuse leaf base. Four sources *viz.*, FCRITK 06, FCRITK 09, FCRITK 11 and FCRITK 13 recorded cuneate leaf base and others registered attenuated leaf base.

Leaf texture: The surface texture of the leaves were categorized into glabrous, coriaceous and scrubber (Fig. 2d). Thirteen sources (43.3%) exhibited coriaceous type of leaf texture followed by scrubber in twelve sources (40%). Five sources *viz.*, FCRITK 09, FCRITK 19, FCRITK 21, FCRITK 26 and FCRITK 28 showed glabrous leaf texture.

Phyllotaxy: There was no difference between the sources in terms of phyllotaxy as all the sources exhibited opposite type.

Leaf attitude: The leaf attitude was categorized into bending and horizontal (Fig. 2j). Seventeen (56.7%) sources exhibited horizontal type and the rest of the sources registered bending type of leaf attitude.

Leaf margin: The leaf margin was only whole in all the observed teak sources.

Leaf margin undulation: The leaf margin undulation was predominantly low in twenty four (80%) sources. Six sources *viz.*, FCRITK 03, FCRITK 04, FCRITK 08, FCRITK 12, FCRITK 14 and FCRITK 25 registered medium undulation.

Leaf brightness: The presence of brightness (Fig. 2e) was observed in twelve (40%) teak sources whereas eighteen (60%) sources exhibited absence of leaf brightness.

Leaf venation: There was no significant difference among the teak sources as all the sources leaf venation touches the margin of the leaf.

Leaf main vein: The main vein of all the teak sources touches the margin of the leaf.

Leaf veins: The leaf veins was categorized into tertiary and quaternary structure (Fig. 2f). Six sources *viz.*, FCRITK 02, FCRITK 05, FCRITK 07, FCRITK 09, FCRITK 10 and FCRITK 20 registered tertiary structure and the rest of the sources (80%) exhibited quaternary structure.

Leaf vein colour: The leaf vein colour was observed as light yellow in two sources (FCRITK 03 and FCRITK 06), yellowish green in nine sources (30%) and light yellowish green in nineteen (63.3%) sources.

Leaf colour:

Adaxial – The leaf colour on adaxial side was categorized as dark green and light green (Fig. 2g). Four sources *viz.*, FCRITK 12, FCRITK 13, FCRITK 15 and FCRITK 27 exhibited light green colour and twenty six sources exhibited dark green colour.

Aboxial – The leaf colour on aboxial side (Fig. 2h) was observed as light greyish green in three sources *viz.*, FCRITK 02, FCRITK 25 and FCRITK 27, light yellowish green in three sources *viz.*, FCRITK 12, FCRITK 13 and FCRITK 29 and light green in rest of the sources.

Leaf pubescence:

Adaxial – The leaf pubescence was absent on the adaxial side of all the teak sources.

Aboxial – The leaf pubescence on aboxial side (Fig. 2i) was observed as present in eleven sources and was found absent in nineteen sources.

Young leaf colour:

Adaxial – The young leaf colour on the adaxial side (Fig. 2k) was sorted as greyish green (FCRITK 01, FCRITK 18 and FCRITK 28), light greenish brown in ten sources, dark greenish brown (FCRITK 13, FCRITK 22, FCRITK 25 and FCRITK 29), light brown in six (20%) sources, dark brown (FCRITK 12, FCRITK 20 and FCRITK 30), green (FCRITK 14 and FCRITK17) and purplish green (FCRITK 09 and FCRITK 21).

Aboxial – The young leaf colour on the aboxial side (Fig. 2l) was sorted as light greyish green (FCRITK 01 and FCRITK 18), light greenish brown in thirteen sources, greenish brown in five sources, light green (FCRITK 14, FCRITK 17, FCRITK 25 and FCRITK 28), light brown (FCRITK 07, FCRITK 19, FCRITK 23 and FCRITK 26) and light purplish green (FCRITK 09 and FCRITK 21).

Stem characterization

Number of internodes: The number of internodes was measured from 1 meter above the ground level and it is grouped into less (4–5), intermediate (5–6) and more (> 6). Twelve sources recorded less number of

internodes followed by more number of internodes in ten sources and intermediate in eight sources.

Internodal length: The internodal length was measured from 1 meter above the ground level and it is categorized into short (13–16 cm), intermediate (16–19 cm) and long (> 19 cm). Eleven sources exhibited short internodal length followed by intermediate in ten sources and long in nine sources.

Trunk spots: There was no difference between the sources in terms of trunk spots as all the sources exhibited presence of trunk spots.

Trunk colour:

Base – All the teak sources exhibited grey colour in the base of the trunk.

Middle – The trunk colour on the middle was observed as light green (FCRITK 12 and FCRITK 17), Dark green in twenty sources and greyish green in eight sources.

Top – The trunk colour on the top was sorted as light green in six sources, green in seventeen sources and greyish green in seven sources.

Genetic similarity and cluster analysis

Through the multivariate analysis by using the UPGMA clustering method four groups at a similarity of 0.5 was obtained (Fig. 1). The group I was formed by seven sources (FCRITK 05, FCRITK 20, FCRITK 21, FCRITK 30, FCRITK 12, FCRITK 13 and FCRITK 29) signifying that these sources have similar leaf attitude and absence of leaf brightness characteristics. Group II was formed with two sources (FCRITK 25 and FCRITK 14) which showed several common attributes, such as adaxial leaf colour, presence of petiole, absence of leaf brightness, leaf margin undulation, absence of leaf pubescence and vein pattern. Group III were formed by six sources (FCRITK 11, FCRITK 26, FCRITK 16, FCRITK 17, FCRITK 15 and FCRITK 27) which exhibited common attributes such as presence of petiole, leaf attitude, leaf margin undulation, leaf brightness and vein pattern. The group IV represented the highest number of sources (15 sources). FCRITK 25 and FCRITK 14 depicted lower similarity in relation to the other sources, with a distance of 0.67. The most similar sources in their morphological characteristics are FCRITK 09, FCRITK 07, FCRITK 05 and FCRITK 20 with a similarity of 0.82.

Discussion

The descriptors are aspect of whole plant or part of plant. Describing the characteristics of a species based on standard descriptors is effective for improved utilization and conservation of germplasm (Fu, 2003). The development of descriptors is essential to differentiate the genetic resources for distinctiveness in each plant trait and for the precise plant database in the crop improvement programmes. 24 morphological descriptors (both qualitative and quantitative) were developed based on the phenotypic assessment of 30 teak seed sources. The teak sources were characterized for leaf (20)

and stem traits (4). These seed sources exhibited a difference in all traits except leaf shape, shape of leaf apex, leaf phyllotaxy, leaf margin, leaf venation, leaf main vein and presence of trunk spots.

Among the 30 seed sources evaluated, the leaf shape was ovate, apex with acute type, the leaf base were obtuse, cuneate and attenuated and with whole leaf margin. The results are in corroboration with Miranda (2013) who investigated the morphological characteristics of teak clones and depicted the leaf shape as elliptical in younger leaves and oval in mature leaves, leaf apex as acute and caudate type, and with corrugated margin. Prasetyawati and A'ida (2019) examined the morphological characters of different provenances of teak and found that the leaf size varied from 10–67 cm in length and 6–52 cm in width, leaf texture as scabber and more scabber, leaf colour as dark green and yellowish green and vein colour as light yellow and yellow in Malabar, Muna and Java provenances which supports the current study.

Most of the morphological characteristics under current investigation are in substantiation with the study of Vinothkumar et al. (2021) who examined 112 germplasm of all India Teak clones for developing morphological descriptors based on 36 Characters and 112 descriptors of different plant parts. Among the 62 teak clones of Karnataka considered for morphometric characters, 40 clones exhibited adaxial pubescence and 22 clones showed non hairy, 28 clones scored rough, 19 scored coarse and 13 scored smooth in leaf texture. Thirty six clones were identified as petiolated and 24 were sessile (Vinutha, 2014). Similar studies on morphological characterization on teak clones at different ages have been carried out in Brazilian countries (Gunaga et al., 2013; Alcântara et al., 2016; Baretta, 2016; Chimello et al., 2017; Betancourt et al., 2020) which attest the findings of the current study.

Morphological descriptors for other commercially important tree species have also been developed. 29 descriptors were developed and documented in *Jatropha* which consist of 13 quantitative characters and 16 qualitative characters (George *et al.*, 2016). 15 descriptors were developed and documented in *Casuarina*, which consist of 7 quantitative characters and 8 qualitative characters (Parthiban et al., 2018). 12 descriptors were developed for kadam based on leaf and bark characteristics (Selvan et al., 2019). 15 descriptors were developed in *Neem* (Gnanasekar and Balasubramanian, 2014). 23 descriptors were developed and documented in *Karanj* (Gnanasekar and Balasubramanian, 2014). 33 descriptors were developed and documented in *Eucalyptus* (Sivakumar et al., 2012).

The descriptors available for the tree species are based on the morphological characteristics of leaves, trunks, branches, flowers, fruits and seeds in general. However, in the current study only morphological characteristics of leaves and stem were evaluated which facilitates to identify the sources at earlier stages, and to enable the protection of teak sources at juvenile stage.

According to the observations made in the dendrogram most of the sources exhibited high similarity. The existence of sources with high similarity shows that only few characteristics will be able to distinguish them which plays a key role in the process of plant protection (Betancourt et al., 2020). In breeding programs, genotypes with similar morphological characteristics experience fewer benefits that result from the combination and genetic gain (Prasetyo et al., 2020) when compared to phenotypically diverse

genotypes (Flôres Junior et al., 2018). Hence, it is essential to envisage the dissimilarity of genotypes to obtain higher genetic gains (Huang et al., 2019).

Conclusion

A total of 24 descriptors based on leaf and stem was developed and documented for 30 teak sources. The sources depicted variability in various morphological traits, which may be considered for conservation of germplasm through IPR mechanism. These descriptors would be helpful to identify and protect the teak genetic resources and would also facilitate as baseline DUS data for varietal registration of Teak sources under Protection of Plant Varieties and Farmer's Rights (PPV&FRA) Authority.

Declarations

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Conflict of interest

All authors declare no conflict of interest.

Author's contribution

Parthiban K.T. conceived, designed and supervised the project, Jawahar Vishnu M.V. conducted research work and data collection; Jawahar Vishnu M.V. and Umesh Kanna S performed statistical analysis; Jawahar Vishnu M.V. drafted the manuscript; Parthiban K.T. and Radhakrishnan S reviewed the draft and suggested technical points to improve the manuscript. Jawahar Vishnu M.V. and edited and revised the final version of the manuscript.

Data Availability Statement

All data generated or analyzed during the current study are included in this published article

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Figures

Figure 1

Dendrogram of similarity of teak sources by UPGMA clustering method based on the Jaccard similarity index.

Figure 2

Morphological variations in leaf characteristics of teak sources