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Characterizing the Morphological Descriptors of Thirty Seed Sources of Teak (*Tectona grandis* L.f.) Concerning Sustainable Forestry

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Abstract: Teak (*Tectona grandis* L.f.) plantations have increased recently in India; however, morphological descriptors for teak are still lacking. Thus, the goal of this work was to develop descriptors based on morphological characteristics. Among 30 seed sources collected from different states of India, 24 morphological descriptors, including 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 color, leaf color, leaf pubescence, young leaf color, number of internodes, internodal length, trunk spots, and trunk color, were developed based on leaf and stem characteristics. 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. The Jaccard similarity index was used to calculate the genetic similarity between the sources, and the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) method was used to perform a cluster analysis (four groups at a similarity of 0.5 were obtained). According to the observations made, most of the sources exhibited high similarity, which indicates that only a few characteristics can be used to distinguish the sources.

Keywords: systematic characterization; morphological variations; cluster analysis; sustainability; timber species; teak

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1. Introduction

Teak (*Tectona grandis* L.f.) has a worldwide reputation as the most valuable tropical timber and is also known as the "King of Timber" [1]. Teak is a Lamiaceae tree native to the Indian–Burmese floristic region, with naturalized populations in India, Myanmar, the Lao People's Democratic Republic, and Thailand, in addition to naturalized populations in Java, Indonesia [2,3]. Since the early 1970s, teak planting activities have intensified due to rising global demand for teak wood and a significant depletion in currently available resources [4]. Choosing the best teak origins remains a critical restriction of maximizing production, especially because timber yields and quality can vary greatly depending on site conditions [4,5]. Genetic diversity and variation are important components of forest resource stability [6]. To aid conservation efforts aimed at preserving species' genetic resources, it is necessary to assess the genetic diversity and genetic divergence of natural populations in native countries.

The increased planted area and the high value of teak wood on the international market has piqued the interest of many foresters and breeders in developing mechanisms that allow the intellectual protection of teak sources. The classification of cultivated plant genotypes is an important step in breeding programs and germplasm conservation and is essential in the process of plant protection. To implement the '*Sui Generis*' system for plant variety protection for granting plant breeding rights (PBRs) to a breeder or farmer or institution, DUS testing is compulsory [7]. A new variety shall be registered if it conforms to the criteria of DUS: distinctness (the variety must be easily distinguished from any other variety whose existence is common knowledge at the time the protection is applied for by one or more essential characteristics), uniformity (the variety is considered uniform if, with the possible exception of variation resulting from the unique characteristics of its propagation, it is sufficiently uniform in the necessary qualities), and stability (the variety is deemed to be stable if its relevant characteristics remain unchanged after repeated propagation) [8]. 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. 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 the morphological characteristics of the leaves and stem were evaluated, which facilitates identification of the sources at earlier stages and enables the protection of teak sources.

Knowledge of the species' morphological diversity is required to develop morphological descriptors for the characterization and management of genetic resources, in addition to the utilization of genetic variability for numerous goals of genetic improvement. The determination of easily visible physical traits of aerial parts would allow the development of an identification key for distinguishing teak seed sources. The goal of this effort was to establish the DUS (distinctiveness, uniformity, and stability) descriptor by selecting an ideal set of morphological descriptors to characterize phenotypic diversity or discriminate clones based on their distinctive states. Although teak is an important timber species, to date, only few studies are available on systematic documentation of the morphological characteristics of teak in India and there are no studies on documentation of the morphological descriptors for massive seed sources of teak collected from the entire teak-growing regions of India, barring a few. Against this backdrop, the current study was conceived to document the morphological variations among the seed sources as a part of a genetic improvement program, which will be helpful in the identification of the sources and to support the plant protection process through the development of descriptors.

2. Materials and Methods

The present study was conducted in a seed source evaluation trial established at Forest College and Research Institute, Mettupalayam (11°19′ N; 76°56′ E; 300 m above MSL) and a seed source evaluation trial established at Punalkulam, Gandarvakottai (10°38′ N; 79°02′ E; 112 m above MSL), representing the western zone and Cauvery Delta Zone, respectively, during 2021–2022. The materials for the present study consisted of 30 seed sources (Table 1) collected from selected plus trees (the seeds were collected from a group of phenotypically superior trees (plus trees), which were selected based on the comparison tree method) of 11 different states, including Tamil Nadu, Tripura, Maharashtra, Odisha, Gujarat, Kerala, Karnataka, Andhra Pradesh, Madhya Pradesh, Chhattisgarh, and Jharkhand (Figure 1). Experimental research and field studies on teak, including the collection of plant material, complied with relevant institutional, national, and international guidelines and legislation.

The collected seeds were sown in raised beds with a medium of red soil, sand, and farm yard manure in a ratio of 2:1:1. The beds were watered at regular intervals and maintained for 6 months. After 6 months, the stumps that were more than 3–4 cm in thickness at the collar region were selected and transplanted into polybags containing a medium of red soil, sand, and farm yard manure (FYM) at a ratio of 2:1:1. After a month of transplantation, the seedlings were planted in the main field. All the seeds were sown simultaneously within a timespan of a week. The assembled seed sources were established in the seed source evaluation trial using a randomized block design (RBD), with

8 plants per plot with 3 replications in an espacement of 4 m × 4 m. Data were collected on the morphological (both quantitative and qualitative) characteristics at 7 months and subsequently at 12 months and the mean data is provided. The type of assessment of the vegetative characteristics was followed as per the standard method prescribed [9].

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 the evaluated teak seed sources with their origin and source code.

S.No.	Place	State	Latitude	Longitude	Assigned Number	Source Code
1.	Nellithurai	Tamil Nadu	11°17′03′′ N	76°51′55′′ E	FCRITK 01	1
2.	Nellithurai	Tamil Nadu	11°17′01′′ N	76°51′55′′ E	FCRITK 02	2
3.	Kallar	Tamil Nadu	11°20′20′′ N	76°52′31′′ E	FCRITK 03	3
4.	Oomapalayam	Tamil Nadu	11°30′35′′ N	76°91′61′′ E	FCRITK 04	4
5.	Kallar	Tamil Nadu	11°20′23′′ N	76°52′20′′ E	FCRITK 05	5
6.	Kallar RF	Tamil Nadu	11°20′24′′ N	76°52′36′′ E	FCRITK 06	6
7.	Agartala	Tripura	23°83′15′′ N	91°28′68′′ E	FCRITK 07	7
8.	Nellithurai	Tamil Nadu	11°16′56′′ N	76°51′58′′ E	FCRITK 08	8
9.	Vilamarathur	Tamil Nadu	11°15′50′′ N	76°50′52′′ E	FCRITK 09	9
10.	Salem	Tamil Nadu	11°66′43′′ N	78°14′60′′ E	FCRITK 10	10
11.	Burliyar	Tamil Nadu	11°34′37′′ N	76°84′04′′ E	FCRITK 11	11
12.	Chandrapur	Maharashtra	19°96′15′′ N	79°29′61′′ E	FCRITK 12	12
13.	Chandrapur	Maharashtra	19°96′15′′ N	79°29′61′′ E	FCRITK 13	13
14.	Chandrapur	Maharashtra	19°96′15′′ N	79°29′61′′ E	FCRITK 14	14
15.	Chandrapur	Maharashtra	19°96′15′′ N	79°29′61′′ E	FCRITK 15	15
16.	Chandrapur	Maharashtra	19°96′15′′ N	79°29′61′′ E	FCRITK 16	16
17.	Chandrapur	Maharashtra	19°96′15′′ N	79°29′61′′ E	FCRITK 17	17
18.	Tanjore	Tamil Nadu	10°78′70′′ N	79°13′78′′ E	FCRITK 18	18
19.	Rairakhol	Odisha	21°04′12′′ N	84°20′60′′ E	FCRITK 19	19
20.	Dang	Gujarat	20°82′54′′ N	73°70′07′′ E	FCRITK 20	20
21.	Nilambur	Kerala	11°28′55′′ N	76°23′86′′ E	FCRITK 21	21
22.	Parambikulam	Kerala	10°37′78′′ N	76°76′42′′ E	FCRITK 22	22
23.	Thenmala	Kerala	8°96′32′′ N	77°06′51′′ E	FCRITK 23	23
24.	Shivamogga	Karnataka	13°92′99′′ N	75°56′81′′ E	FCRITK 24	24
25.	Valsad	Gujarat	20°59′92′′ N	72°93′42′′ E	FCRITK 25	25
26.	Dandeli	Karnataka	15°23′61′′ N	74°61′73′′ E	FCRITK 26	26
27.	Khandwa	Madhya Pradesh	21°83′14′′ N	76°34′98′′ E	FCRITK 27	27
28.	Vizianagaram	Andra Pradesh	18°10′67′′ N	83°39′56′′ E	FCRITK 28	28
29.	Raipur	Chhattisgarh	21°25′14′′ N	81°62′96′′ E	FCRITK 29	29
30.	Ranchi	Jharkhand	23°34′41′′ N	85°30′96′′ E	FCRITK 30	30

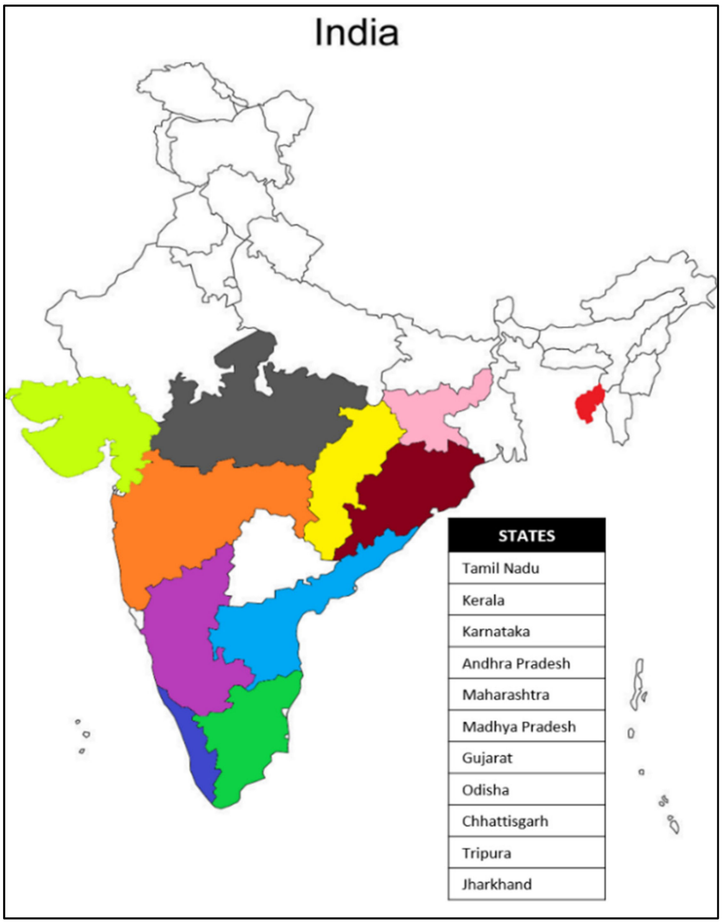

Figure 1. Map depicting the states from which teak seed sources were gathered.

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 using the UPGMA method (Unweighted Pair Group Method with Arithmetic mean) by means of Past 4.03 software [10].

3. Results

The DUS traits of 30 teak sources were characterized in order to protect the genetic resources through a potential IPR mechanism. The stem and leaf characteristics of the teak sources were characterized, where the expression of the morphological variations among the sources was similar at two locations. The consolidated results are presented in Tables 2 and 3. Significant variation was recorded among the teak genetic resources for the following 24 characteristics: 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 color, leaf color, leaf pubescence, young leaf color, number of internodes, internodal length, trunk spots, and trunk color.

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
		Scabrous	12 (40%)	5, 12, 13, 14, 15, 16, 17, 20, 25, 27, 29, 30
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

Table 2. *Cont.*

S.No	Characteristics	Levels of Expression		Distribution of Classes	Source Code
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 Color	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 Color	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
		Abaxial	Greyish green	8 (26.6%)	1, 3, 11, 16, 17, 19, 20, 26
			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
		Abaxial	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 Color	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
		Abaxial	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
			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 (measured from 1 m above the ground level)	4–5		12 (40%)	1, 3, 6, 7, 14, 16, 17, 22, 25, 27, 29, 30
		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 (measured from 1 m above the ground level)	13–16 cm		11 (36.7%)	3, 4, 6, 8, 9, 11, 12, 15,18, 21, 28
		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 Color	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
		Middle	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
			Greyish green	8 (26.6%)	5, 11, 13, 15, 16, 20, 25, 29
		Top	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

3.1. Leaf Characterization

3.1.1. Leaf Length and Width

The leaf length was grouped into short (40–50 cm), medium (50–60 cm), and long (>60 cm). Fifteen sources (50%) exhibited a medium leaf length followed by ten sources (33.3%) under the long category and five sources (16.7%) exhibited a short leaf length. The leaf widths of the teak sources were categorized into short (30–40 cm), medium (40–50 cm), and long (50–60 cm). In total, 56.7% of the sources recorded a medium leaf width followed by long (26.6%) and short (16.7%) (Table 2).

3.1.2. Presence of Petiole

Twenty-six (86.7%) sources were petiolate. Four sources viz., FCRITK 01, FCRITK 05, FCRITK 21 and FCRITK 30 exhibited sessile leaf. The leaf petiole length of teak was categorized into three groups, including short (2–4 cm), intermediate (4–6 cm), and wide (6–8 cm) (Figure 2a,b). Thirteen sources (43.4%) exhibited a wide petiole length followed by intermediate (30%) in nine sources and short in four sources (13.3%) (Table 2).

3.1.3. Leaf Shape Attributes

All the teak sources predominantly exhibited an ovate leaf shape and registered an acute leaf apex. The base shapes of the teak leaf samples were grouped into three categories, including obtuse (the leaf base is blunt to rounded), cuneate (wedge-shaped), and attenuated (the leaf base is broad to narrowly tapering) (Figure 2c). Twenty-two (73.4%) sources exhibited an obtuse leaf base. Four sources, including FCRITK 06, FCRITK 09, FCRITK 11, and FCRITK 13, recorded a cuneate leaf base and others registered an attenuated leaf base. The surface texture of the leaves was categorized into glabrous, coriaceous, and scabrous (Figure 2d). Thirteen sources (43.3%) exhibited the coriaceous type of leaf texture followed by scabrous in twelve sources (40%). Five sources, including

FCRITK 09, FCRITK 19, FCRITK 21, FCRITK 26, and FCRITK 28, showed a glabrous leaf texture. There was no difference between the sources in terms of phyllotaxy as all the sources exhibited the opposite type. The leaf attitude was categorized into bending and horizontal (Figure 2j). Seventeen (56.7%) sources exhibited a horizontal type and the rest of the sources registered a bending type of leaf attitude (Table 2).

(a). Presence and absence of petiole

(b). Variation in petiole length

(c). Variation in shape of leaf base

(d). Variation in leaf texture (scabrous and glabrous)

(e). Presence and absence of leaf brightness

(f). Leaf vein pattern (quaternary and tertiary)

(g). Variation in adaxial leaf color

(h). Variation in abaxial leaf color

(i). Presence and absence of leaf pubescence

(j). Variation in leaf attitude (horizontal and bending)

Figure 2. *Cont.*

(**k**). **Variation in adaxial young leaf color**

(**l**). **Variation in abaxial young leaf color**

Figure 2. Variations in the (**a**) presence and absence of petiole, (**b**) petiole length, (**c**) shape of leaf base (variation in leaf vein color), (**d**) leaf texture attitude (horizontal and bending), (**e**) presence and absence of petiole, (**f**) leaf vein pattern, (**g**) adaxial leaf color, and (**h**) abaxial leaf color (**i**) presence and absence of leaf pubescence, (**j**) leaf attitude (horizontal and bending), (**k**) adaxial young leaf color, and (**l**) abaxial young leaf color.

3.1.4. Leaf Margin and Brightness

The leaf margin was only whole in all the observed teak sources. Leaf margin undulation (the characteristic that makes a leaf hard to flatten or press) was predominantly low in 24 (80%) sources. Six sources, including FCRITK 03, FCRITK 04, FCRITK 08, FCRITK 12, FCRITK 14, and FCRITK 25, registered medium undulation. The presence of brightness (Figure 2e) was observed in 12 (40%) teak sources whereas 18 (60%) sources exhibited an absence of leaf brightness. There was no significant difference among the teak sources as all the sources leaf venation touched the margin of the leaf (Table 2).

3.1.5. Leaf Veins

Leaf veins were categorized into tertiary and quaternary structures (Figure 2f). Six sources, including FCRITK 02, FCRITK 05, FCRITK 07, FCRITK 09, FCRITK 10, and FCRITK 20, registered a tertiary structure and the rest of the sources (80%) exhibited a quaternary structure. The main vein of all the teak sources touched the margin of the leaf. The leaf vein color was observed as light yellow in 2 sources (FCRITK 03 and FCRITK 06), yellowish green in 9 sources (30%), and light yellowish green in 19 (63.3%) sources (Table 2).

3.1.6. Leaf Color

The leaf color on the adaxial side was categorized as dark green and light green (Figure 2g). Four sources, including FCRITK 12, FCRITK 13, FCRITK 15, and FCRITK 27, exhibited a light green color and twenty-six sources exhibited a dark green color.

The leaf color on the abaxial side (Figure 2h) was observed as light greyish green in three sources, including FCRITK 02, FCRITK 25, and FCRITK 27; light yellowish green in three sources, including FCRITK 12, FCRITK 13, and FCRITK 29; and light green in the rest of the sources (Table 2).

3.1.7. Leaf Pubescence

Leaf pubescence was absent on the adaxial side of all the teak sources. Whereas leaf pubescence on the abaxial side (Figure 2i) was observed in eleven sources and was found to be absent in nineteen sources (Table 2).

3.1.8. Young Leaf Color

The young leaf color on the adaxial side (Figure 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 FCRITK 17), and purplish green (FCRITK 09 and FCRITK 21) (Table 2).

The young leaf color on the abaxial side (Figure 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) (Table 2).

3.2. Stem Characterization

The number of internodes was measured from 1 m above the ground level, and it was grouped into less (4–5), intermediate (5–6), and more (>6). Twelve sources recorded less internodes followed by more internodes in ten sources and intermediate in eight sources. The internodal length was measured from 1 m above the ground level and it was categorized into short (13–16 cm), intermediate (16–19 cm), and long (>19 cm). Eleven sources exhibited a short internodal length followed by intermediate in ten sources and long in nine sources (Table 3).

There was no difference between the sources in terms of trunk spots as all the sources exhibited the presence of trunk spots. All the teak sources exhibited a grey color at the base of the trunk. The trunk color on the middle was observed as light green (FCRITK 12 and FCRITK 17), dark green in twenty sources, and greyish green in eight sources. The trunk color on the top was sorted as light green in six sources, green in seventeen sources stem and leaf characteristics, and greyish green in seven sources (Table 3).

3.3. Genetic Similarity and Cluster Analysis

Through the multivariate analysis using the UPGMA clustering method, four groups with a similarity of 0.5 were obtained (Figure 3). 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 a 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 color, presence of petiole, absence of leaf brightness, leaf margin undulation, absence of leaf pubescence, and vein pattern. Group III was formed by six sources (FCRITK 11, FCRITK 26, FCRITK 16, FCRITK 17, FCRITK 15, and FCRITK 27), which exhibited common attributes such as the presence of petiole, leaf attitude, leaf margin undulation, leaf brightness, and vein pattern. 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 were FCRITK 09, FCRITK 07, FCRITK 05, and FCRITK 20, with a similarity of 0.82 (Figure 3).

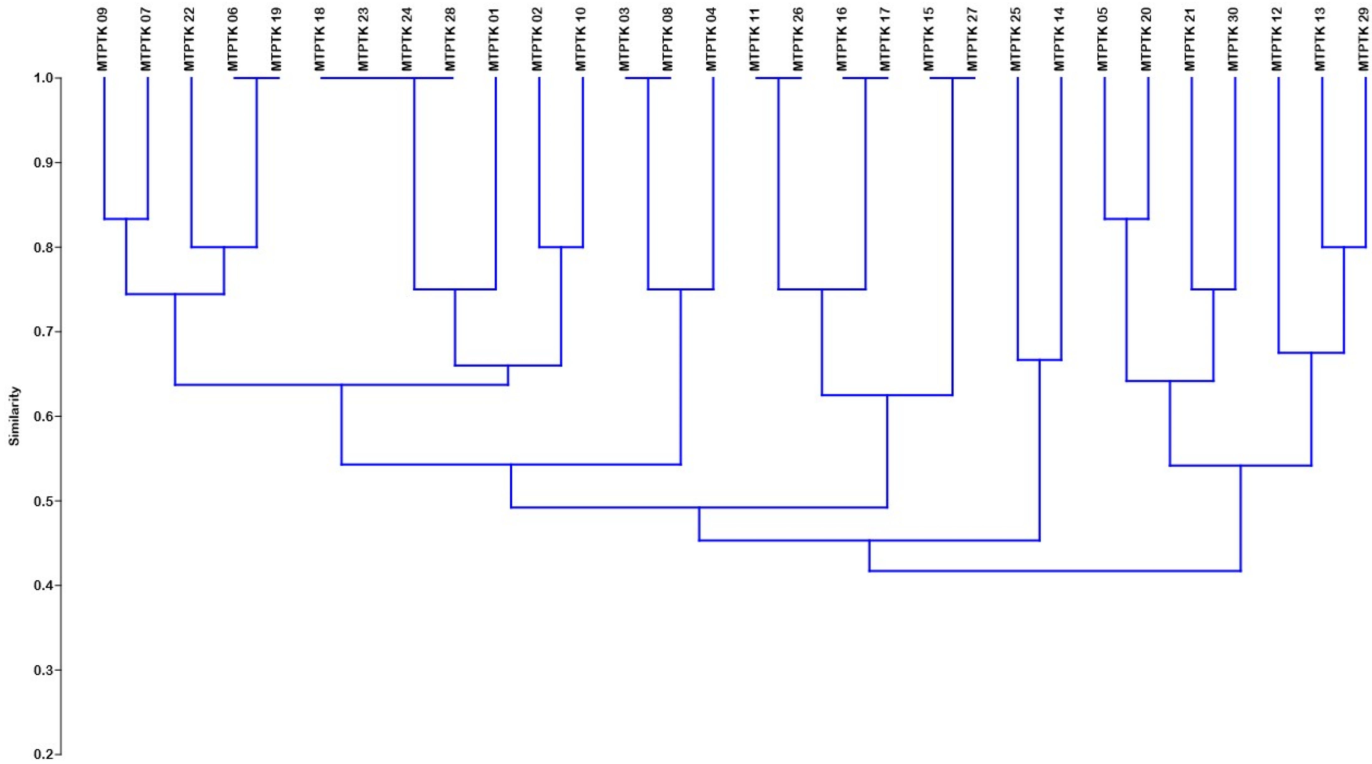

Figure 3. Dendrogram of the similarity of teak sources by the UPGMA clustering method based on the Jaccard similarity index.

4. Discussion

The descriptors are the aspect of the whole plant or part of the plant. Describing the characteristics of a species based on standard descriptors is effective for improved utilization and conservation of germplasm [11]. The development of descriptors is essential to differentiate genetic resources for distinctiveness in each plant trait and for a precise plant database in crop improvement programs. In total, 24 morphological descriptors (both qualitative and quantitative) were developed based on the phenotypic assessment of 30 teak seed sources. The teak sources were characterized by 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, the apex was the acute type and the leaf base was obtuse, cuneate, and attenuated with a whole leaf margin. The results are in corroboration with the morphological characteristics of teak clones, which depicted the leaf shape as elliptical in younger leaves and oval in mature leaves, the leaf apex as acute and the caudate type, and with a corrugated margin [12]. The examination of the morphological characteristics of different provenances of teak found that the leaf size varied from 10–67 cm in length and 6–52 cm in width, leaf texture as scabrous and more scabrous, leaf color as dark green and yellowish green, and vein color as light yellow and yellow in the Malabar, Muna, and Java provenances [13], which supports the current study.

Most of the morphological characteristics in the current investigation substantiate the results of an earlier study [14], where 112 germplasm of all India teak clones were examined for the development of morphological descriptors based on 36 characteristics and 112 descriptors of different plant parts. Among the 62 teak clones studied in Karnataka for morphometric characteristics, 40 clones exhibited adaxial pubescence, 22 clones were non-hairy, 28 clones were rough, 19 clones were coarse, 13 had a smooth leaf texture, 36 clones were petiolated, and 24 were sessile [15]. Similar studies on morphological characterization of teak clones at different ages have been carried out in Brazilian countries [16–20], which support the findings of the current study.

Morphological descriptors for other commercially important tree species have also been developed. In total, 29 descriptors were developed and documented in Jatropha, which consisted of 13 quantitative and 16 qualitative characteristics [21]. Fifteen descriptors were developed and documented in Casuarina, which consisted of seven quantitative and eight qualitative characteristics [22]. Twelve descriptors were developed for Kadam based on leaf and bark characteristics [23]. Fifteen descriptors were developed in Neem [24]. In total, 23 descriptors were developed and documented in Karanj [25] while 33 descriptors were developed and documented in Eucalyptus [26].

For teak, only the morphological traits of the leaves and stem were assessed while it is recommended that the morphological traits of the inflorescence should also be included. However, all of the sources did not have inflorescence at the assessed ages, which made analysis difficult.

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 a few characteristics can distinguish them, which plays a key role in the process of plant protection [20]. The similarity between the sources might be due to their origin and environmental factors due to which the sources have evolved into a landrace with a distinct genetic pattern and structure. Moreover, in breeding programs, genotypes with similar morphological characteristics experience fewer benefits that result from the combination and genetic gain [27] when compared to phenotypically diverse genotypes [28]. The genetic factor has a greater influence on the morphological features than the geographical features [28]. Hence, it is essential to envisage the dissimilarity of genotypes to obtain higher genetic gains [29]. However, the present study was carried out only during the juvenile stage in the leaves and stem. Even the future researches can consider studying the other early stage morphological measurements [30–33] to strength the comparing results. Moreover, growth characteristics can also be studied further in different growth periods to achieve variability and facilitate the development of DUS data for varietal registration.

5. Conclusions

A total of 24 characteristics based on the leaf and stem were studied in 30 teak sources. Among the 24 characteristics studied, 17 characteristics, including leaf length, leaf width, presence of petiole, petiole length, shape of leaf base, leaf texture, leaf attitude, leaf margin undulation, leaf brightness, leaf venation, leaf vein color, leaf color, leaf pubescence, young leaf color, number of internodes, internodal length, and trunk color, showed significant differences. These features may be useful as preliminary information in the formulation of characterization descriptors for genetic breeding programs under the Protection of Plant Varieties and Farmer's Rights (PPV&FRA) Authority and can be considered for the conservation of germplasm through the IPR mechanism.

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