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Plus tree selection of *Casuarina equisetifolia* L. in eastern coastal plain of Odisha

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Abstract

Casuarina equisetifolia L. commonly called whistling pine is an economically and industrially important tree species with global significance. Although species possess versatile importance worldwide, efforts imparted for selection and designing a robust model of selection index are inadequate. The selection process, based on quantitative and qualitative traits, identified 15 superior trees from the eastern coastal plain of Odisha. These superior trees showcased exceptional qualitative and quantitative attributes. Correlation analysis highlighted key similarities among various traits like volume and above ground biomass (AGB), volume and diameter at breast height (DBH), DBH and AGB, DBH and Tree Height (TH), crown length (CL), height, AGB and height. Principal component analysis emphasized substantial contributions of traits like DBH, height, CL, crown width, AGB and volume across different clusters. Furthermore, culmination resulted in a comprehensive selection index, integrating both qualitative and quantitative characters, reaching 52.04, signifying superior performance among specific accessions. The current study provides valuable insights into selection and designing optimal selection index of *C. equisetifolia*, guiding future decisions concerning optimal wood production and resource management.

Introduction

Ever increasing population and rapid decrease in quality stock are creating pressure as well as disturbances on forest stands. Ministry of Commerce and Industry, India, pointed out an increase in imports of wood and wood products nationwide from 1149.28 USD million in 2018 to 1454.52 USD million in 2019 (Global Agricultural Information Network, 2019). The demand is further likely to increase with the advancement of technologies and ease of trade and tariffs. To fulfil this gap, raising short-rotation and fast-growing species is essential. Additionally, such species could prove themselves as a crucial keystone for conservation and mitigating climate change. Hence, there is necessary to adopt fast-growing species like *Casuarina equisetifolia* L., coupled with high productivity, greater biomass, short rotation and wider adaptability.

C. equisetifolia commonly known as whistling pine, Australian pine, beefwood and Jhaun (Pinyopusarerk and Williams, 2000) belonging to the family Casuarinaceae can grow up to a height of 20 m (66 ft) in just 12 years, and may thrive in a variety of soil conditions (Liu *et al.*, 2014). *C. equisetifolia*, regardless of its origin as an introduced species from Australia is widely distributed across India, especially in states like Andhra Pradesh, Odisha, Karnataka, Tamil Nadu and the Union Territory by covering a plantation area exceeding 500,000 ha (Nicodemus, 2009). Being a fast-growing woody plant species *C. equisetifolia* has the potential to serve as a source of fibre for the pulp and paper industries (Dechamma *et al.*, 2020). *Casuarina* is hailed as the finest firewood globally, ignites easily and yields excellent charcoal (El-Lakany, 1983). Furthermore, it acts as a primary raw source for crafting house posts, rafters, electric poles, tool handles, oars, wagon wheels and mine props (Orwa, 2009). Additionally, *C. equisetifolia* is characterized by medicinal properties like antimicrobial effects (antibacterial and antifungal effect), antidiabetic and antihyperlipidemic activity, antioxidant effect, antidiarrheal activity, cytotoxic effect, nephroprotective effect and hepatoprotective effect (Al-Snafi, 2015; Gowrie, 2018). Its suitability for interplanting with agricultural crops is lauded for improving soil quality through leaflitter deposition (Reddy, 2001). Moreover, it restricts soil erosion and restores soil deterioration in coastal areas such as West Bengal, Orissa and Kerala by reducing wind speed and fixing atmospheric nitrogen (Kim *et al.*, 2020). Recently, India has claimed the title of foremost producer of *Casuarina* globally

(Pinyopusarerk and Williams, 2000). Striking phenotypic variations has been reported on this particular species throughout its distributional range in India (Kondas, 1983). Abundant individual tree variation often observed in terms of growth and various morphometric characters (Warrier and Venkataramanan, 2011).

The selection of promising individuals is the foremost breeding step that determines the degree of success achieved by the programme. However, in both self and cross-pollinated plants, it is complex to identify the best superior distinct parents from the base population. Selection not only provides insights into the spectrum of variations and genetically controlled traits within the species but also provides a platform for future tree improvement strategies. Similarly, morphometric techniques, on the other hand, confirm complex variation within genotypes and have long been established as valuable tools for distinguishing heterogeneous populations and exploring plant development. Realizing the versatile importance and substantial phenotypic variations, efforts imparted for the selection and designing a robust model of selection index model for this particular species concerning deciduous forests are inadequate. Therefore, it needs systematic investigation and multifold research activities to unveil crucial information and select superior accessions of *C. equisetifolia* in the eastern coastal plain of Odisha. Keeping the preceding in mind, the present investigation was intended to elucidate the morphological characteristics, identify promising individuals and structure the selection index for *Casuarina* by considering both qualitative and quantitative data.

Materials and methodology

Study area

In the present study, selection was conducted from an available population of *C. equisetifolia* situated in the coastal district of Odisha, particularly focusing on the Puri district within the geographic coordinates of 19°28′ to 20°10′ north latitude and 85°09′ to 86°25′ east longitude. A total of nine sections within the Puri Wildlife Division were systematically considered for identifying plus trees. Each studied location, along with its corresponding geographic coordinates and climatic data, was meticulously recorded as detailed in Table 1 and Fig. 1.

Plus tree selection

In each wildlife range, trees surpassing 30 cm girth at breast height (GBH) were considered. Selection of plus trees followed a baseline or regression method as outlined by Kim *et al.* (2020). It involves plotting crown volume $[(Crown\ Width)^2 \times Crown\ Length]$ on the X-axis as an independent variable and trunk volume (Moor, 2020) $[(DBH)^2 \times Height]$ on the Y-axis as dependent variables. Subsequently, the selected plus trees underwent an assessment based on qualitative traits for the final declaration of plus trees. For better selection, repeated regression was followed wherever necessary, and each location was analysed separately for selecting plus tress.

Table 1. Sampled sites for the selection of plus trees

Sl. no.	Range	Locations	Geographic location	Rainfall details (mm)	Temperature details
1	Balukhand	Balukhand	85°59′49″E 19°51′04″N	1318.21	34°C (maximum), 16°C (minimum)
		Satyabadi	85°48′35″E 19°57′10″N		
		Balighai	85°56′19″E 19°51′34″N		
		Puri Sadar	85°49′10″E 19°48′16″N		
2	Bramhagiri	Harachandi	85°37′48″E 19°47′24″N	1451.6	33°C (maximum), 17°C (minimum)
		Bramhagiri	85°59′49″E 19°51′04″N		
		Sunamuhin	85°47′06″E 19°49′35″N		
3	Gop	Gop	86°21′24″E 19°56′32″N	1398.8	34°C (maximum), 15°C (minimum)
		Nimapada	86°25′40″E 20°03′13″N		
4	Astaranga	Jahania	86°16′52″E 19°55′54″N	1619.2	35°C (maximum), 15°C (minimum)
		Daluakani	86°16′09″E 19°55′32″N		
5	Konark	Konark	86°05′36″E 19°53′31″N	1457.7	36°C (maximum), 15°C (minimum)
		Chandrabhaga	86°06′55″E 19°51′58″N		

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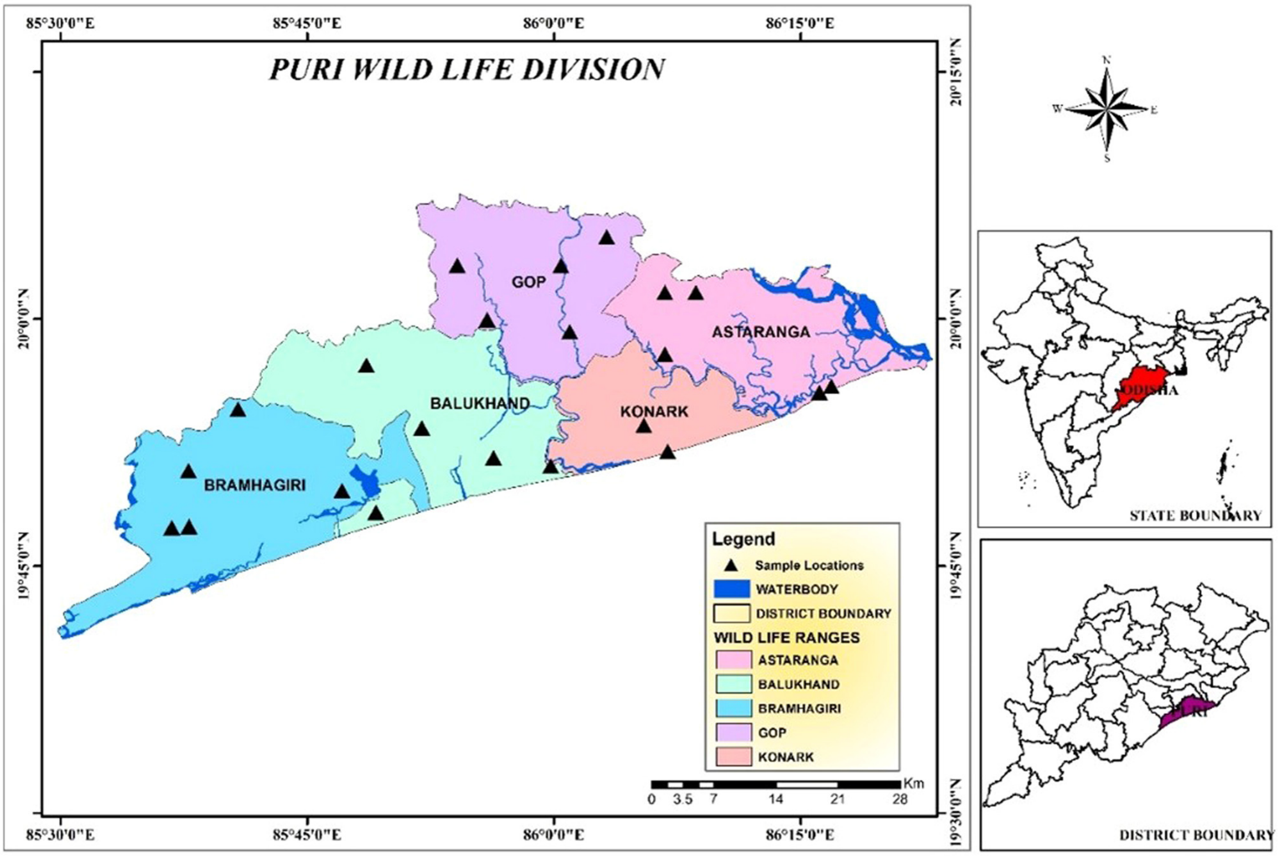

Figure 1. Map of Puri Wildlife Division along with study site.

Quantitative measures

The field data encompassing tree height (TH) and clear bole height (CBH) were determined through range finder. GBH was calculated by taking two perpendicular measurements at 1.37 m above the ground using a caliper. Crown width and crown length (CL) were assessed by following Schomaker (2007) as presented in supplementary material, Plate 1. Subsequently, above ground biomass (AGB) and overall tree volume were measured as referenced by Brahma *et al.* (2021) and Kumar (1995), respectively.

Qualitative measures

The qualitative measures were conducted through meticulous observation and the score was assigned according to the predefined characteristics (Supplementary material, Table). The scores were allocated considering the economic interest of industrial

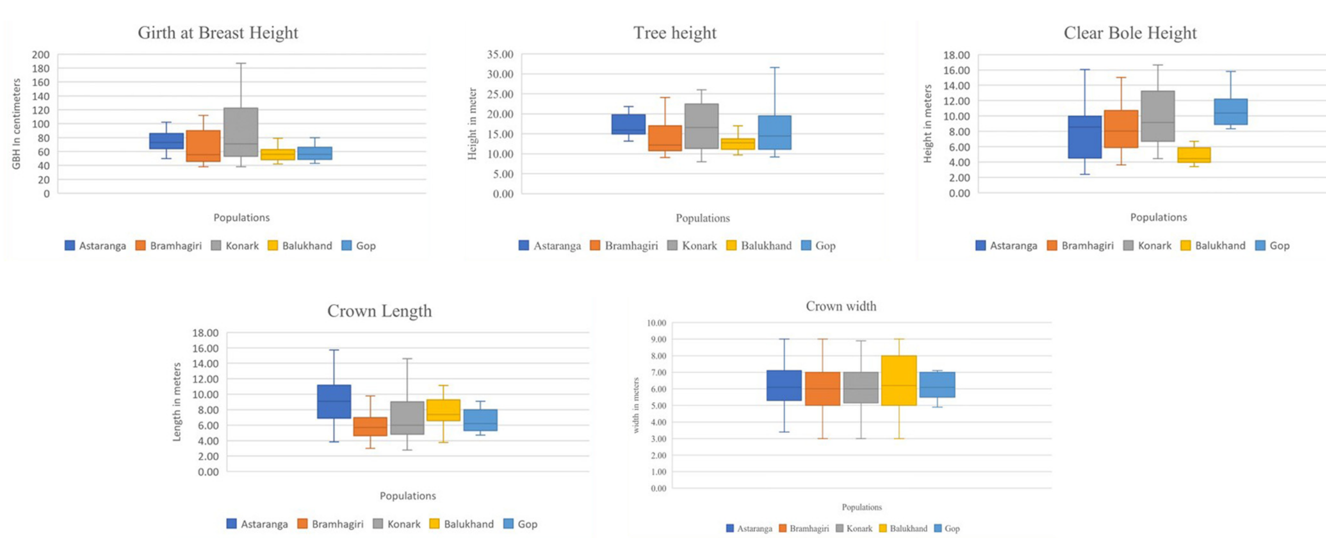

Figure 2. Morphological characterization of individuals across the Puri Wildlife Division: girth at breast height (a), TH (b), clear bole height (c), CL (d), crown width (e).

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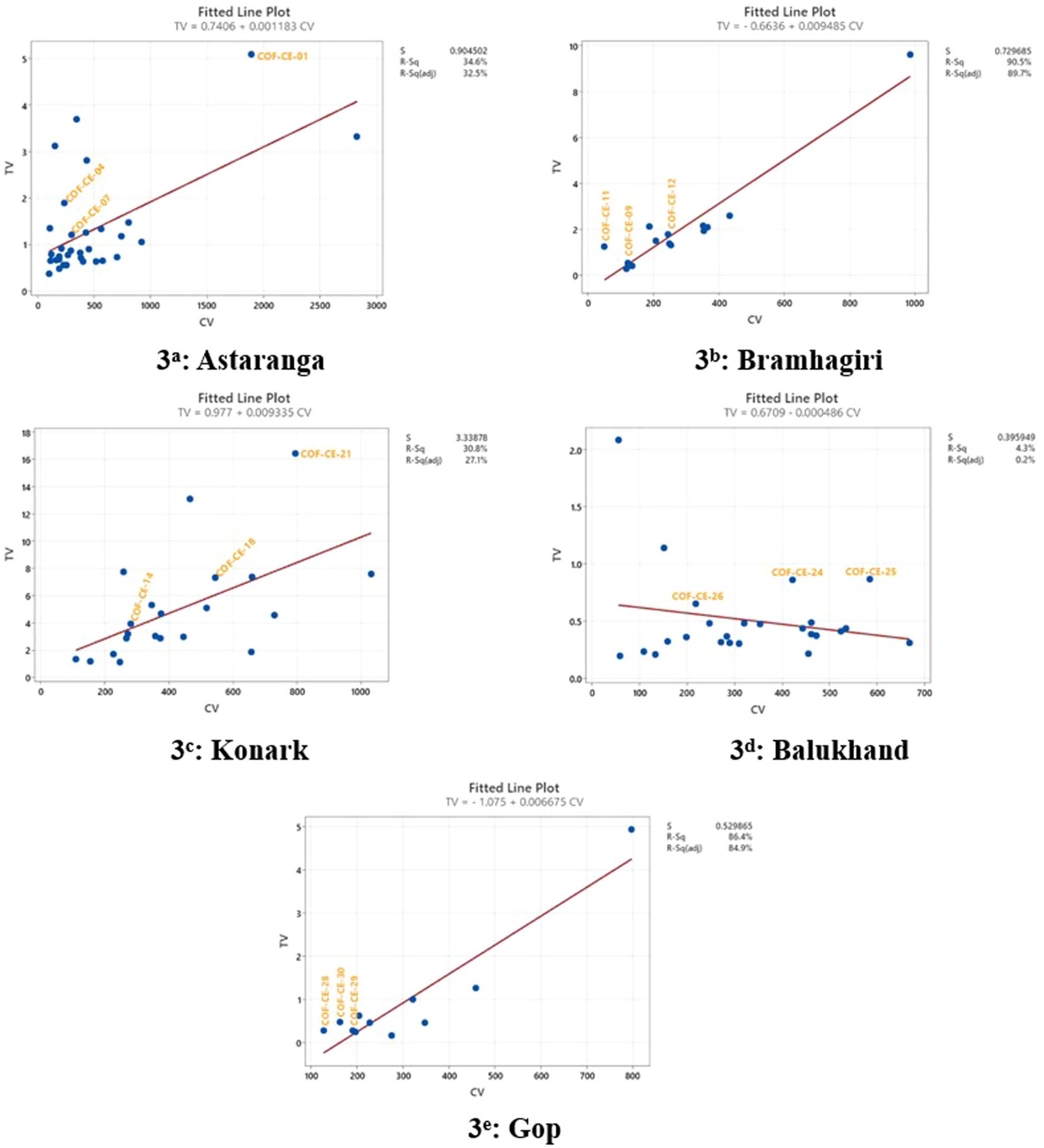

Figure 3. Regression analysis of *C. equisetifolia* trees (Astaranga (a), Bramhagiri (b), Konark (c), Balukhand (d) and Gop (e)).

usage. The characteristics such as straightness, apical dominance, forking, crookedness, self-pruning ability, stem damage, bole swelling and branching behaviour were taken into consideration.

Statistical analysis

The data collected were employed for understanding the variation in terms of phenotypic observations. Correlation among quantitative traits was performed using Minitab software based on squared Euclidean distance. Principal component analysis (PCA) of the plus trees was plotted using R Software and a selection index was developed considering three principal components which explained 70% of the cumulative variation (Moor, 2020).

Results

The phenotypic traits analysed in this study showed significant variation owing to environment and genetics, as indicated by

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Table 2. Morphological characters of fifteen plus trees of *C. equisetifolia*

Locality	Sl. No.	Tree number	Accession number	Geographical location		CBH (m)	GBH (m)	Total height (m)	CL (m)	CW (m)
				Latitude	Longitude					
Astaranga	1	AS01	COF-CE-01	19.95751	86.269471	16.06	1.02	34.96	18.19	10.00
	2	AS04	COF-CE-04	19.954686	86.269021	13.64	0.97	19.87	6.23	6.20
	3	AS07	COF-CE-07	19.931217	86.283758	4.86	0.89	15.24	10.30	5.40
Bramhagiri	4	BM03	COF-CE-09	19.79004	85.6788775	10.73	0.59	15.64	4.91	5.00
	5	BM14	COF-CE-11	19.812534	85.769981	8.94	0.93	17.27	8.33	5.00
	6	BM17	COF-CE-12	19.81411	85.756858	12.23	0.9	22	9.77	5.00
Konark	7	KO01	COF-CE-14	19.995279	86.009576	14.98	2.5	25.98	11.00	8.50
	8	KO05	COF-CE-18	19.89513	86.084154	14.59	2.39	22.66	8.07	7.60
	9	KO08	COF-CE-21	19.890493	86.094621	16.64	1.71	24.75	8.11	8.20
Balukhand	10	BK03	COF-CE-24	19.828047	85.901241	6.69	0.79	13.62	6.93	7.80
	11	BK04	COF-CE-25	19.827876	85.901312	6.12	0.75	15.24	9.12	8.00
	12	BK07	COF-CE-26	19.828306	85.901811	4.50	0.7	13.25	8.74	5.00
Gop	13	GP05	COF-CE-28	20.042936	86.009286	8.91	0.53	10.21	4.70	5.20
	14	GP06	COF-CE-29	20.023487	86.008	9.75	0.49	12.1	5.30	6.00
	15	GP09	COF-CE-30	20.0651	86.037012	10.44	0.65	11.37	5.40	5.50

GBH, girth at breast height; CBH, clear bole height; CW, crown width; CL, crown length.

Zobel and Talbert (1984). The findings of the current study revealed significant dissimilarities among the populations.

General characteristics of C. equisetifolia *individuals considered for selection*

The phenotypic characters of individuals in each study range were assessed for the selection of plus trees. In the Puri Wildlife Division, observation of general characteristics of the *C. equisetifolia* is shown in Fig. 2. A total of 160 trees were enumerated from all localities representing Puri provenance which represented a mean GBH of 102.90 cm, height of 18.59 m and CBH of 11.97 m. Each location exhibited varying tree counts, reflecting the distribution and density of the tree population in Astaranga (32), Bramhagiri (43), Konark (49), Balukhand (25) and Gop (11).

The results revealed diverse GBH values across locations, ranging from 38 to 250 cm. The higher maximum GBH was reported by the Konark population (250 cm) followed by Bramhagiri (185 cm) and Astaranga (135 cm). The highest minimum girth of 59 cm was recorded in Astaranga followed by Gop and Konark (43 cm) (Fig. 2(a)). This variance underscores the differing sizes and, potentially, the local environment of the trees in the surveyed areas. Total height, expressed in m, signifies the vertical extent of the trees. The measurements span from 8 to 34.96 m, showcasing the vertical diversity in tree structures across the sampled locations. These variations may result from the ecological conditions of each area. The height of trees assessed in the Astaranga location was spread about 13.55 m. CBH characterizes the length of the clear trunk portion devoid of branches. The dataset indicates a range from 3.39 to 27.84 m, offering insights into the extent of unbranched trunk sections and potential variations in tree architecture among the populations. The minimum CBH among the populations as illustrated in Fig. 3(c) ranged from 3.61 m (Bramhagiri) to 13.6 m (Astaranga). The crown dimensions, encompassing length and width in m, delineate the horizontal and vertical spreads of the tree canopy. Observations across provenances as mentioned in Figs. 3(d) and (e) revealed differences in crown structures, with lengths ranging from 3 m (Bramhagiri) to 19.61 m (Astaranga) and widths varying between 3 m (Balukhand, Bramhagiri) and 10 m (Astaranga).

Plus tree selection

In the current study, plus trees were selected in two phases. In the first phase, based on the baseline method, in which better trees with vigour were selected based on their crown volume to trunk volume relationship. In the second phase, trees were enumerated based on the scoring of qualitative characters. A total of 15 plus trees of *C. equisetifolia* were selected following the regression method (Supplementary material, Plate 2). The selection considered qualitative characters (straightness, apical dominance, forking, crookedness, self-pruning ability, stem damage, bole swelling and branching behaviour) and quantitative characters (GBH, CBH, height, CL, crown width, volume and AGB). During the preparation of the regression graph of quantitative characters such as crown volume and trunk volume were considered. The R^2 value ranged from 0.905 to 0.43. The trees placed above the baseline with the highest quantitate characters were selected as plus trees (Table 2) and scores for qualitative characters are shown in Table 3.

A total number of seven trees (COF-CE-01, COF-CE-02, C0F-CE-03, COF-CE-O4, COF-CE-05, C0F-CE-06 COF-CE-07) fell above the baseline in the Astaranga range (Fig. 3(a)) and from a qualitative aspect COF-CE-01, COF-CE-04 and C0F-CE-07 had the highest scores 32, 30, and 30, respectively (Table 3). Regression analysis of 43 trees from the Bramhagiri range with an R^2 value of 0.57 indicated a total of 14 trees as candidate plus tree (CPT), to select the best out of these 14 trees were used for

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Table 3. Scoring of *C. equisetifolia* based on qualitative traits

Sl. No.	Tree Id no.	Location	Straight ness	Apical dominance	Forking	Crookedness	Self-pruning ability	Stem damage	Bole swelling	Branching behaviour	Total scoring
1	COF-CE-01	Astaranga	5	3	5	5	3	5	5	2	33
2	COF-CE-04		4	5	5	3	4	5	4	3	33
3	COF-CE-07		4	3	5	4	4	3	4	5	32
4	COF-CE-09	Bramhagiri	4	4	3	5	3	5	5	5	34
5	COF-CE-11		5	5	5	5	4	4	5	5	38
6	COF-CE-12		4	4	5	5	5	5	5	4	37
7	COF-CE-14	Konark	2	4	2	2	3	4	2	5	24
8	COF-CE-18		3	3	3	2	3	3	3	4	24
9	COF-CE-21		2	4	2	2	3	1	2	5	21
10	COF-CE-24	Balukhand	3	3	1	5	4	1	5	3	25
11	COF-CE-25		1	3	3	5	3	1	5	3	24
12	COF-CE-26		1	2	2	5	3	1	5	3	22
13	COF-CE-28	Gop	5	2	5	5	2	2	3	3	27
14	COF-CE-29		4	3	4	4	3	3	1	2	24
15	COF-CE-30		4	5	5	3	3	4	3	4	31

Table 4. PCA for expressing component contributions of traits

Parameter	PC1	PC2	PC3
CBH	−0.431	−0.159	0.037
GBH	−0.442	0.111	0.106
Total height	−0.418	−0.144	−0.310
CL	−0.241	−0.095	−0.518
CW	−0.363	0.165	−0.330
Straightness	0.087	−0.444	0.001
Apical dominance	−0.143	−0.356	0.309
Forking	0.108	−0.447	−0.006
Crookedness	0.379	−0.091	−0.370
Self-pruning ability	0.037	−0.298	−0.045
Stem damage	−0.116	−0.502	0.019
Bole swelling	0.199	−0.156	−0.377
Branching behaviour	−0.129	−0.091	0.371
Standard deviation	1.986	1.761	1.498
Proportion of variance	0.3033	0.2386	0.1727
Cumulative proportion	0.3033	0.5419	0.7145

regression by repeating the method. As a result, a total of six trees were placed above the baseline with an R^2 value of 0.905 (Fig. 3(b)). These six trees named COF-CE-08, COF-CE-09, COF-CE-10, COF-CE-11, COF-CE-12 and COF-CE-13, which exhibited a score of 30, 34, 33, 38, 37 and 28, respectively, for qualitative characters (Table 4). Similarly, regression analysis of 50 trees in the Konark range showed around 22 trees above the baseline with an R^2 value of 0.48 (Fig. 3(c)). Those initially selected 22 individuals had to be rescreened and ultimately eight trees (COF-CE-15, COF-CE-16, COF-CE-17, COF-CE-18, COF-CE-19, COF-CE-20, COF-CE-21) were screened with an R^2 score of 0.308 (Fig. 3(c)). In the Gop, a total of five trees were selected by regression analysis with R^2 value is 0.864 (Fig. 3(d)). Trees COF-CE-27, COF-CE-28, COF-CE-29, COF-CE-30 and COF-CE-31 with scores of 24, 27, 24, 31 and 23 were selected, respectively. Regression analysis of 25 trees from Balukhand had an R^2 value was 0.043 ($P < 0.05$) (Fig. 3(e)). A total number of five trees, COF-CE-22, COF-CE-23, COF-CE-24, COF-CE-25 and COF-CE-26 were nominated and the score was allotted i.e. 21, 22, 25, 24 and 22, respectively. Finally, from each location three trees having the highest score were selected and 15 trees were considered as plus trees.

Quantitative and qualitative characterization of selected PTs

The quantitative characters observed for plus trees are provided in Table 2. Among the selected trees the maximum CBH measured was 16.64 m (COF-CE-21) and the minimum was 4.50 m (COF-CE-26). GBH ranged from 2.5 m (COF-CE-14) to 0.49 (COF-CE-29) with an average of 1.16 m. The average value for height of plus trees was 20.14 m, the maximum height was 34.96 m (COF-CE-01) and minimum height was 10.21 m (COF-CE-28). The average CL of plus trees was 8.52 m with a maximum value recorded for COF-CE-01 (18.19 m), whereas a minimum of 4.70 m (COF-CE-28). The maximum crown width was

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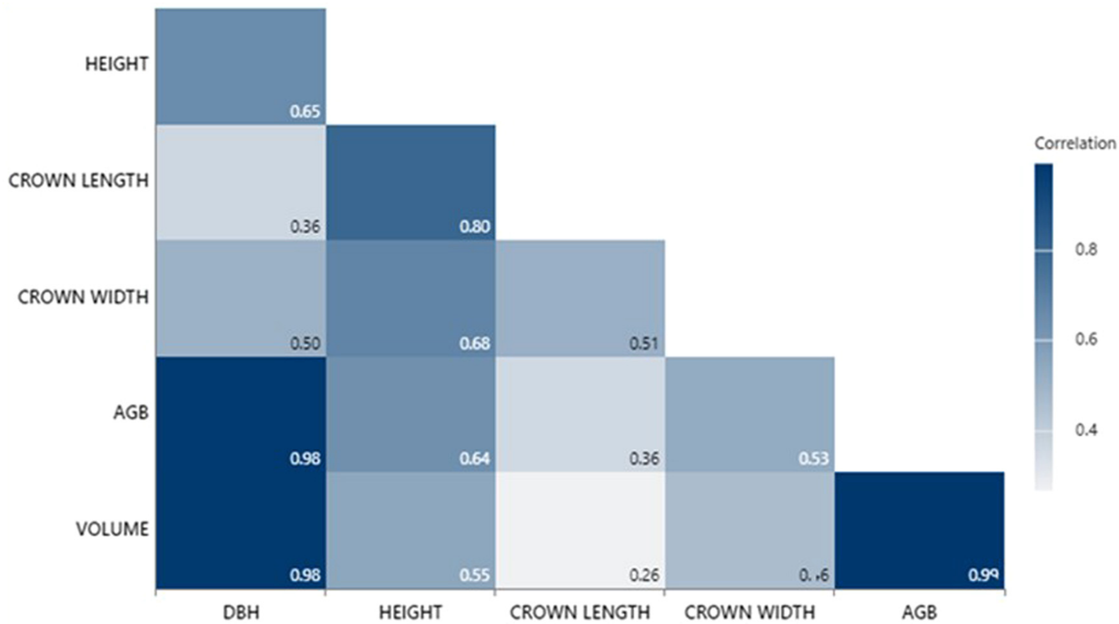

Figure 4. Correlogram shows correlation among quantitative characters of CPTs of *C. equisetifolia*.

10.00 m (COF-CE-01) and the minimum was 5.0 m (COF-CE-09, 11, 12 and 26). Subsequently, scoring was carried out for qualitative characteristics. Table 3 shows scoring of qualitative characters of plus trees screened from five different locations.

A correlogram between all the quantitative characters is plotted to show the correlation among the quantitative traits studied (Fig. 4). A substantial positive correlation was observed between diameter at breast height (DBH) and volume ($r = 0.98$), DBH and AGB ($r = 0.98$) and AGB and volume (0.98) at the 0.01 level. All the traits had shown a positive correlation indicating an increasing trend in development. Furthermore, crown characters showed a very weak correlation with economic traits such as height, GBH and volume.

PCA and selection index

PCA indicates the importance of the largest contributor to the total variation at each axis of differentiation. The scree plot in Fig. 5 clearly illustrates that three principal components were able to explain 70% of total variation. Among the components, PC1 explained 30.3% of variation followed by PC2 with 23.9% and PC3 accounted for 17.3%. As a first component, tree

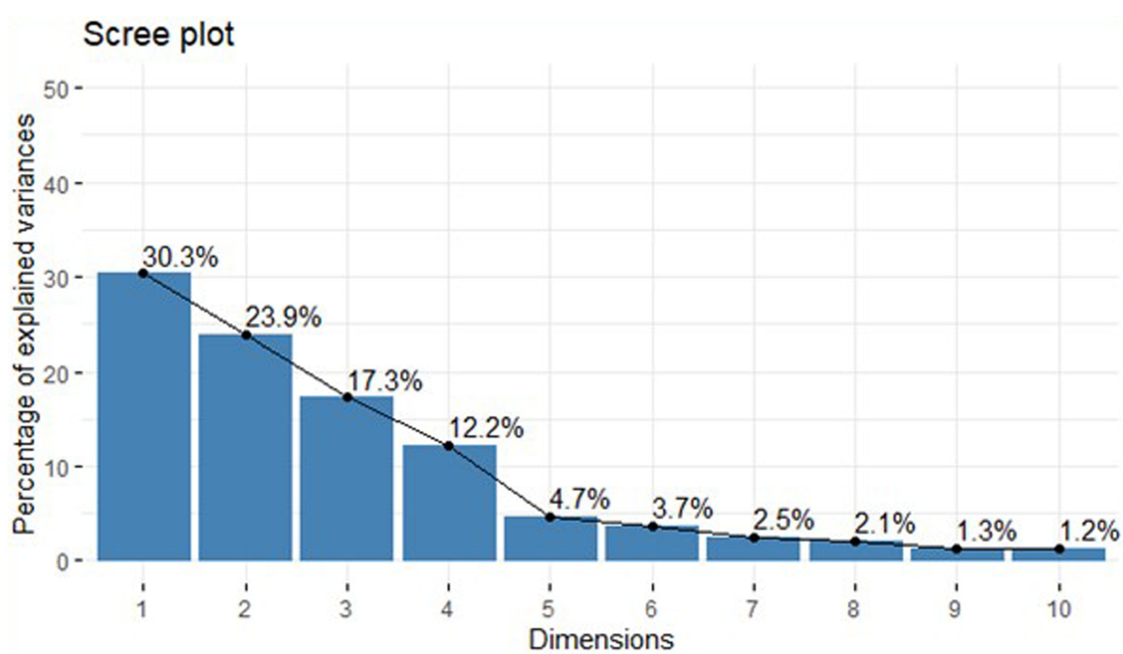

Figure 5. Scree plot showing a cumulative variation of principal components.

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Table 5. Selection index score of superior accessions

Accessions	Index score	Rank
COF-CE-01	659.80	4
COF-CE-04	258.11	5
COF-CE-07	162.65	8
COF-CE-09	86.46	12
COF-CE-11	209.42	7
COF-CE-12	247.10	6
COF-CE-14	2052.14	1
COF-CE-18	1641.55	2
COF-CE-21	930.36	3
COF-CE-24	123.73	10
COF-CE-25	125.32	9
COF-CE-26	97.13	11
COF-CE-28	49.28	15
COF-CE-29	51.70	14
COF-CE-30	78.39	13

straightness, forking, crookedness, self-pruning ability and bole swelling had positive loading values, whereas all of these parameters had negative loading values in PC2 (Table 4).

The standard deviation of PC1, PC2 and PC3 was 1.986, 1.761 and 1.498, respectively. Subsequently, these three components were considered to construct a robust selection index model aimed at enhancing the classification of plus trees and to develop the most suitable and robust model for future application of this species in coastal plain areas. The derived selection index for the eastern coastal plain of Odisha is as follows:

Selection index:

0.383 × DBH + 0.477 × height + 0.263 × CL + 0.156 × crown width + 0.368 × AGB + 0.333 × volume + 0.119 × straightness + 0.334 × apical dominance + 0.101 × forking + (−0.46) × crookedness + 0.134 × self-pruning ability + 0.427 × stem damage + (−0.165) × bole swelling + 0.193 × branching behaviour

Additionally, the selection index for plus trees was computed by utilizing loading values obtained from PC1, PC2 and PC3 of PCA (Table 5). The selection index indicated that accession number COF-CE-14 had the maximum selection weightage (2052.14) followed by COF-CE-18 with 1641.55 considering dedicated weightage for each trait by PCA. Similarly, individual biplot of accessions based on the morphological traits, evident that the accession COF-CE-01 is different among the individuals selected, whereas the accessions COF-CE-14, 18 and 21 fall under one category and they also share the index score between 39 and 43 (Fig. 6). Similarly, the accessions having lower index values ranging from 18 to 22.5 formed a single cluster having accessions COF-CE-25, 26, 28, 29 and 07. Reaming accessions were categorized as intermedium clusters of higher and lower selection index values.

Discussion

The selection of *C. equisetifolia* involved evaluating phenotypic characteristics of 160 trees from the Puri provenance. These trees had a mean GBH of 102.90 cm, height of 18.59 m and CBH of 11.97 m. GBH values ranged from 38 to 250 cm, and THs ranged from 8 to 34.96 m. CBH varied from 3.39 to 27.84 m, and crown dimensions ranged from 3 to 19.61 m in length and 3 to 10 m in width. These variations highlight differences in tree sizes and local environments, likely influenced by both genetic and micro-environmental factors. It was conducted in relatively restricted geographic areas, where atmospheric and edaphic features such as climate, soil type and topography were largely uniform. Substantial variation among individual trees suggests that genetic constitution plays a crucial role in shaping phenotypic outcomes. It also highlights the potential interplay between genetic diversity and micro-environmental factors.

In a comparable investigation conducted by Prasad and Sagheer (2010) on natural populations of *Dipterocarpus indicus* from various regions of the Western Ghats, the researchers associated the variation in growth parameters with differing rainfall and latitudinal conditions. Corresponding findings were noted by Sharma *et al.* (2017) in *Dalbergia sissoo*, and Pande *et al.* (2013) in *Leucaena leucocephala* across 24 populations in Andhra Pradesh, Tamil Nadu and Orissa. Environmental factors

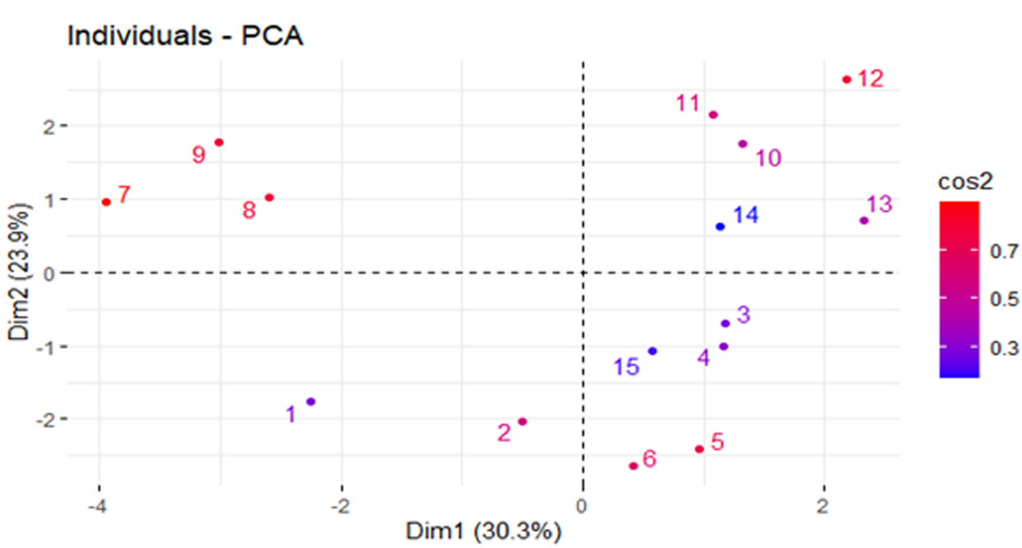

Figure 6. Individual biplot of selected accession showing distant relationship.

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mainly rainfall, temperature and humidity play a crucial role in shaping the variation, which is helpful in the selection of provenances for breeding (Ashwath *et al.*, 2020). However in managed environments, the variation found can be attributed to genetic effects rather than climatic conditions as they experience similar growing environments. Meanwhile, evidence supports the notion that prolonged exposure to specific environmental factors leads to phenotypic changes in tree species. These adaptations are critical for the success of trees in diverse habitats.

Assessing and understanding variation is crucial in tree breeding programmes as higher degrees of diversity present opportunities for selection. Selection of hardwood using baseline method or regression discusses total variation in the phenotypic characters of species which is incurred by inherent and environmental influence. The current study screened a total of 15 *C. equisetifolia* trees using the regression method, considering both qualitative and quantitative characteristics. Qualitative traits such as straightness, apical dominance, forking, crookedness, self-pruning ability, stem damage, bole swelling and branching behaviour, along with quantitative traits like GBH, CBH, height, CL, crown width, volume and AGB were assessed. Similarly, selection of *Melia dubia* plus trees was carried out through a regression analysis involving the parameters of (DBH) × height and (crown width) × CL (Binu and Santhoshkumar, 2018). Moor (2020) made a selection of *Swietenia macrophylla* population in north Kerala by considering a total of 598 candidates and regression values ranged from 0.58 to 0.78. Daneva *et al.* (2018) selected 21 plus trees of *Ailanthus excelsa* Roxb. from Haryana, Rajasthan and Gujarat based on qualitative characteristics like self-pruning ability, stem straightness, disease resistance, branching habit, clean bole height, etc. Similarly, *A. excelsa* (Daneva *et al.*, 2018), *Azadirachta indica* (Dhillon *et al.*, 2003) and *D. sissoo* (Yadav *et al.*, 2005) have seen successful selections based on qualitative traits. Correlation among the growth traits was observed in tree species as they are the characters interlinked during the growth period (Chauhan *et al.*, 2018).

Among the screened trees, the maximum CBH measured was 16.64 m (COF-CE-21), while the minimum was 4.50 m (COF-CE-26). GBH ranged from 2.5 m (COF-CE-14) to 0.49 m (COF-CE-29), with an average of 1.16 m. The average height of plus trees was 20.14 m, with the maximum height recorded at 34.96 m (COF-CE-01) and the minimum at 10.21 m (COF-CE-28). Discrepancies in these measurements may arise from genetic factors, geographical conditions such as soil and irradiance, altitude variations and may be due to differences in silvicultural practices. The results were in line with Chauhan *et al.* (2018), who observed tree morphological character of *M. dubia* changed with soil and other site characters. Most of the qualitative characters are reported to show variation due site adaptability of the species by altering the morphological appearance, whereas some characters may be genetically influenced. Therefore, it requires to be tested to assess the genetic worthiness of each individual.

PCA attempts to simplify interrelationships among a large set of variables in terms of a relatively small set of variables or components without losing any necessary information from the data. Subsequently, a selection model was developed aimed at enhancing the classification of plus trees and optimizing future selection of this species in the coastal plain areas of Odisha. This comprehensive approach helps in capturing and interpreting the primary factors contributing to the variation within the dataset under study. Additionally, the selection model conserves time and effort for subsequent tree improvement activities in recent future. The analysis revealed that three principal components effectively explained 70% of the total variation, as depicted in the scree plot. The loading values of individual parameters at PC1, PC2 and PC3 were used to calculate the selection index score. The results highlighted that accession COF-CE-14 had the highest selection weightage (2052.14), followed by COF-CE-18 with a score of 1641.55. These values demonstrate the importance of these particular accessions in the selection process. Similar selection indices have been developed for other species, such as *S. macrophylla* (Moor, 2020), *Melia azedarach* (Dhillon *et al.*, 2009) and *Taxodium distichum* (Wang *et al.*, 2019) which support the efficacy of our approach. According to Chahal and Gosal (2002), characters with the largest absolute values within the first principal component significantly influence the analysis. Thus, the differentiation of accessions into various clusters was due to the high contribution of a few key characters. This index allows for the prioritization and selection of trees with desirable traits for future breeding and improvement efforts. Building on these findings, our study's comprehensive approach provides a foundation for future research and practical applications in tree breeding and resource management.

Conclusion

The selected trees from the naturalized location exhibited significant variation among the studied parameters, confirming the effectiveness of our selection process. Using regression analysis and the baseline method, 15 trees were selected based on their quantitative and qualitative traits. The selection index, calculated using PCA, confirmed that accession COF-CE-14 had the highest selection weightage, followed by COF-CE-18. These results underscore the potential for future research to include molecular evaluation, wood properties characterization, clonal performance and genotype–environment interaction studies to further enhance the species' improvement.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1479262124000534

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