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RESEARCH ARTICLE

Soil-driven physiological and biometric traits in *Ceiba pentandra* (L. Gaertn) via cleft grafting and seed propagation in Southern India

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Abstract

Ceiba pentandra, a multipurpose tree species, is widely utilized in agroforestry and afforestation projects. Evaluating its growth in diverse soil types via sexual and asexual propagation is essential for its promotion in various ecological regions. Thus, the current study was carried out to assess the growth of kapok in Tamil Nadu black soil and red laterite soil. Seeds for sexual propagation and scion wood for asexual propagation (cleft grafting) of *Ceiba pentandra* were obtained from four superior trees in Coimbatore and Theni districts. Six-month-old nursery-raised seedlings were used as rootstock. Seeds were sown and cleft grafting was conducted in February 2023. Both seedlings and grafts were transplanted to two study locations in September 2023. Significant variations in biometric parameters among different sources, soil types and propagation techniques were observed. CP-29 ramet recorded maximum height, volume index, greater photosynthetic rate and relative water content. Significant correlations between growth attributes and physiological traits were documented in the current study. Positive correlation between photosynthetic rate, number of leaves and stomatal conductance were noted. Principal component analysis (PCA) revealed that principal component 1 (PC1) accounted for 59.7% of the total variability and PC2 accounted for 35.1%. Ramets established through cleft grafting in black soil have shown favourable growth. Thus, the CP29 and MTP01 exhibited superior performances based on growth traits.

Keywords

cleft grafting; correlation; principal component; transplanted

Introduction

Ceiba species, which belong to Malvaceae and the subfamily Bombacoideae, are native to the Neotropics' seasonally dry tropical forests, encompassing regions such as Central America, the Caribbean and South America (1). Most *Ceiba* species typically attain heights between 5 and 20 meters. However, *Ceiba pentandra* (kapok) is an exception, with individuals reaching heights of 30 to 50 meters. Its introduction into Asia is debated, with no clear consensus. It has been hypothesized in some accounts that the Portuguese may have transported the species from

America to Africa and subsequently introduced it to Asia (2). This species typically reaches 25 to 40 m in India, influenced by the region agro-climatic conditions. Tamil Nadu is primarily grown in semiarid areas such as Coimbatore, Salem, Theni, Dindigul, Dharmapuri and Madurai. Theni district boasts the largest cultivation area, covering around 4,650 hectares (3). The fruit of kapok is harvested for floss, which is utilized in stuffing pillows, mattresses and cushions. It also serves as an excellent insulating material for iceboxes, refrigerators, cold storage facilities, offices, theatres and aeroplanes.

Additionally, kapok is an effective sound absorber used in acoustic insulation and is particularly valuable in hospitals as mattresses can be dry sterilized without losing quality. The seeds contain 20-25% non-drying oil, used in lubricants and soap production, while the pressed cake, with about 26% protein, is utilized as cattle feed. The wood, which has a specific gravity of 0.25 g/cm^3, makes plywood, packaging, lumber core stock, light construction, pulp and paper products, match splints, canoes and rafts. Due to its diverse applications, the species is often cultivated along farm boundaries and in social forestry plantations (4). This species is also preferred in agroforestry for its straight bole, acute branching, deciduous nature and early production of high-quality floss and seeds (5).

The total environment of a crop is a complex integration of physical and biological elements. Soil plays a critical role in delivering essential nutrients required for plant growth, except for those derived from the atmosphere, such as carbon from carbon dioxide and some oxygen. Additionally, soil acts as a moisture reservoir and provides the anchorage medium for trees. Soil attributes, including chemical composition, texture, structure, depth and position, significantly influence tree growth by affecting the availability of moisture and nutrients. Numerous studies have demonstrated strong correlations between site productivity, tree growth and soil characteristics. The physical, chemical and biological characteristics of soil affect the plant physiological, biological and chemical properties that influence the growth, yield and quality of plant biomass (6). Among these transformations, physiological attributes, mainly photosynthetic characteristics, are vital measurable indicators of plant growth. Understanding the variation in photosynthetic parameters and their relationship with growth traits provides insights into underlying processes and responses, which is valuable for tree improvement programs (7). Photosynthetic activity and gas exchange provide valuable understandings of the energy balance of plants. These factors, transpiration, stomatal conductance and leaf chlorophyll content, are particularly significant because they can be measured directly on living organs. This direct measurement allows for accurate assessments of the physiological condition of a tree. Physiological tests of plant vitality are crucial as they detect low-vigour or damaged plants likely to exhibit poor performance when transplanted into different sites.

The establishment of Kapok (*Ceiba pentandra*) plantations has been observed to enhance soil fertility regimes. Moreover, ecophysiological studies on different *Ceiba* species have revealed their resistance to adverse environmental conditions. It has shown drought resistance through its high sapwood water storage capacity. Previous studies reported the vegetable propagation of kapok by branch cutting, using macro-somatic and micro-somatic propagation (8, 9). Cleft grafting, recognized as a modern technique, is widely and successfully practiced globally. Hence, the current study evaluated the growth of kapok in Tamil Nadu black soil and red laterite soil, utilizing both cleft grafting and seed propagation methods. Assessing the species' compatibility with these specific soil types is crucial for thriving plantations and it aims to measure kapoks' biometric and ecophysiological responses in these environments.

Materials and Methods

Study area

The research trial was conducted at two distinct districts under the western agroclimatic zone of Tamil Nadu. The first experimental site was a farmers' field in Samanaickenpalayam, Coimbatore district (11.17° N, 76.97° E). It is characterized by black soil. It has a hot semiarid climate under the Koppen classification, with a wet season from September to November influenced by the northeast monsoon. Mean maximum temperatures range from 29.2°C to 35.9°C, while mean minimum temperatures vary from 9.8 °C to 24.5 °C. It receives an average annual rainfall of approximately 600 mm, with the northeast monsoon contributing 47% and the southwest monsoon accounting for 28% of the total precipitation. The second experimental site was located at the Horticulture College and Research Institute in Periyakulam, Theni district (10.07 °N 77.33 ° E), which features red-laterite soil. The region has a salubrious climate, receiving northeast monsoon rains from October to December. Summer temperatures peak at 40 °C and drop to 26.3 °C, while winter temperatures range between 29.6 °C and 18 °C. The area averages an annual rainfall of approximately 830 mm.

Cultural practices and experimental design

Seeds for sexual propagation and scion wood for asexual propagation (cleft grafting) of *Ceiba pentandra* were sourced from four superior trees in farmers' fields in Coimbatore and Theni districts. Six-month-old kapok seedlings raised in a nursery were utilized as rootstock. The seeds were sown and cleft grafting was performed in February 2023. After six months, in September 2023, both the seedlings and ramets were transplanted to the two study locations. Soil samples were collected from both places to analyze soil chemical properties (Table 1). The experiment was designed as a three-factorial Randomized Block Design (FRBD), with soil types (black and red laterite) as one factor, propagation technique (seedling and cleft grafting) as the second factor and plant sources (MTP01, CP28, CP29 and CP30) as the third factor. Six plants per plot were planted with three replications at 5 m × 5 m spacing. Appropriate guidelines and regulations conducted all analyses.

Growth biometrics

Biometric observations were carried out at two intervals: three months after planting (3MAP) and six months after planting (6MAP). The measured parameters included plant height, basal diameter, number of leaves and volume index. Plant height (cm) was recorded using a measuring tape, basal diameter (mm) was measured with a Vernier calliper and the volume index (cm^3) was calculated (10) as follows in Equation 1:

Volume index (cm^3) = height (cm) × basal diameter^2 (cm^2) (Eqn. 1)

Table 1. Soil chemical properties

Properties	Samanaickenpalayam (Black soil)	Periyakulam (Red -laterite soil)
Soil reaction (pH)	8.24	7.65
Soil Electrical Conductivity (dS/m)	0.16	0.12
Available Soil Nitrogen (kg/ha)	250.4	231.5
Available Soil Phosphorus (kg/ha)	23.2	24.9
Available Soil Potassium (kg/ha)	257.5	226.7
Soil Organic Carbon (%)	0.58	0.42

Ecophysiological attributes

Gas exchange parameters, including net photosynthetic rate (Pn), stomatal conductance (Gs) and transpiration rate (Tr), were measured using a Li-6400 photosynthetic system (Li-Cor, Inc., Nebraska, USA). Measurements were taken from fully mature and expanded leaves from each replication between 10:00 and 12:00 hours.

Intrinsic water-use efficiency (iWUE) was calculated as the ratio of net photosynthesis to stomatal conductance and expressed in units of µmol/mol (11). Additionally, instantaneous water-use efficiency was assessed as the ratio of net photosynthetic rate to transpiration rate (12). These measurements were conducted six months after planting (6MAP).

Estimation of leaf water status

Physiologically functional leaves were collected and processed into uniformly sized leaf discs. These discs were then assessed for fresh, dry and turgid weight. Leaf relative water content (RWC) was determined using the standard method as given in Equation 2 (13):

RWC = 100 × [(fresh weight - dry weight) / (turgid weight - dry weight)] (Eqn. 2)

Chlorophyll was extracted from 0.25 g of fresh leaf samples using 80% acetone. The extracts' absorbance was measured spectrophotometrically at 475 nm, 645 nm and 663 nm. The total chlorophyll content was determined using the standard method (14).

Statistical analysis

The analysis of variance (ANOVA) was conducted (15) for a three-factorial randomized block design (FRBD). Biometric, physiological and biochemical parameters were analyzed for mean differences using Duncans' Multiple Range Test (DMRT) at a 5% significance level. Pearsons' correlation coefficients were also calculated. Both analyses were performed using the core package of R statistical software version 4.3.2 (16). Additionally, a biplot was created to visualize the PCA results using R software.

Results

Variations in biometric parameters and ecophysiological traits

The variance analysis results presented in Table 2 indicate significant differences across biometric parameters and ecophysiological traits. Substantial variations in biometric parameters among different sources, soil types and plant materials were observed three months and six months after planting (Table 3-4). These differences were identified using Duncans' multiple comparison test at the 0.05 significance level. The study evaluated the survival rates and growth metrics of different genotypes in various soil types over three months. The genotype CP29 exhibited the highest survival rate at three months (80.92%), whereas CP30 had the lowest (71.92%). Survival rates in black soil (76.71%) and red laterite soil (76.29%) were comparable. Plant height among the genotypes ranged from 45.33 cm to 33.83 cm three months after planting (3 MAP) and from 53.83 cm to 43.08 cm six months after planting (6MAP).

Black soil recorded the maximum plant heights of 44.87 cm at 3MAP and 54.75 cm at 6MAP. Ramets outperformed seedlings in plant height, achieving 42.04 cm at 3 MAP and 51.50 cm at 6 MAP, compared to seedlings, which measured 36.67 cm at 3 MAP and 45.50 cm at 6 MAP. Additionally, basal diameter and volume index were more significant in black soil, measuring 10.30 mm and 48.07 cm^3 at 3 MAP and 11.16 mm and 70.02 cm^3 at 6MAP, as opposed to red laterite soil, which recorded 8.44 mm and 25.71 cm^3 at 3 MAP and 8.96 mm and 35.81 cm^3 at 6 MAP.

Table 2. Variance analysis (ANOVA) of biochemical parameters, physiological parameters and ecophysiological traits among kapok sources.

Source of variation	Height		Basal diameter		No. of leaves		Volume index		Photosynthetic rate		Transpiration rate		Stomatal conductance		Total chlorophyll		Relative water content	
	F value	P value	F value	P value	F value	P value	F value	P value	F value	P value	F value	P value	F value	P value	F value	P value	F value	P value
Replication	1.61	0.21^{ns}	6.33	0.0**	1.49	0.240^{ns}	4.04	0.027*	3.07	0.06^{ns}	18.23	0.0**	8.0	0.0**	0.27	0.75^{ns}	36.24	0.0**
Genotype	3.15	0.03*	6.19	0.0**	9.68	0.0**	8.74	0.0**	29.54	0.0**	20.38	0.0**	77.0	0.0**	125.74	0.0**	64.54	0.0**
Site	20.12	0.0**	45.94	0.0**	0.06	0.795^{ns}	53.95	0.0**	12.66	0.0**	54.61	0.0**	30.0	0.0**	8.53	0.0**	36.96	0.0**
Plant type	4.63	0.03*	97.68	0.0**	1.29	0.264^{ns}	34.25	0.0**	370.84	0.0**	105.61	0.0**	71.0	0.0**	20.04	0.0**	11.00	0.0**
Genotype × site	0.85	0.47^{ns}	3.46	0.02*	1.00	0.403^{ns}	3.46	0.028*	0.24	0.86^{ns}	0.92	0.44^{ns}	2.0	0.13^{ns}	0.10	0.95^{ns}	0.33	0.79^{ns}
Genotype × plant type	0.89	0.45^{ns}	2.42	0.08^{ns}	4.01	0.016*	1.37	0.269^{ns}	0.97	0.41^{ns}	0.15	0.92^{ns}	3.0	0.04*	0.93	0.43^{ns}	0.41	0.74^{ns}
Site × plant type	7.91	0.08**	28.31	0.0**	1.29	0.264^{ns}	10.91	0.002**	2.01	0.16^{ns}	1.92	0.17^{ns}	3.0	0.09^{ns}	0.0	1.0^{ns}	4.27	0.04*
Genotype × site × plant type	0.376	0.77^{ns}	0.10	0.95^{ns}	2.67	0.064^{ns}	0.13	0.938^{ns}	0.84	0.47^{ns}	1.00	1.0^{ns}	0.0	1.0^{ns}	0.79	0.50^{ns}	0.47	0.70^{ns}

**Highly significant difference at p< 0.001 level of probability and ns = no significance

Table 3. Growth parameters after three months of planting (3 MAP)

Treatments	Survival	Plant height (cm)	Basal diameter (mm)	Number of leaves	Volume index (cm^3)
Sources					
MTP01 (S_1)	75.16^{c}	42.50^{a}	9.89^{a}	10.50^{a}	45.74^{a}
CP28 (S_2)	78.00^{b}	33.83^{b}	8.96^{b}	8.08^{b}	28.12^{b}
CP29 (S_3)	80.92^{a}	45.33^{a}	10.14^{a}	10.42^{a}	45.88^{a}
CP30 (S_4)	71.92^{d}	35.75^{b}	8.50^{b}	8.07^{b}	27.79^{b}
SEm±	0.28	2.21	0.31	0.34	3.34
SEd±	0.40	3.12	0.44	0.48	4.72
CD (at 5%)	0.83	6.38	0.91	0.98	9.63
Soil type					
Laterite soil (ST_1)	76.29^{a}	33.83^{b}	8.44^{b}	9.04^{a}	25.71^{b}
Black soil (ST_2)	76.71^{a}	44.87^{a}	10.30^{a}	9.50^{a}	48.07^{a}
SEm±	0.20	1.57	0.23	0.23	2.35
SEd±	0.28	2.21	0.32	0.33	3.33
CD (at 5%)	0.58	4.49	0.63	0.68	6.81
Plant material					
Ramet (P_1)	76.58^{a}	42.04^{a}	10.37^{a}	9.37^{a}	41.83^{a}
Seedling (P_2)	76.42^{a}	36.67^{b}	8.37^{b}	9.16^{a}	31.94^{b}
SEm±	0.21	1.56	0.22	0.24	2.36
SEd±	0.27	2.22	0.31	0.34	3.34
CD (at 5%)	0.59	4.51	0.65	0.69	6.82

Table 4. Growth parameters after six months of planting (6 MAP)

Treatments	Plant height (cm)	Basal diameter (mm)	Number of leaves	Volume index (cm^3)
Sources				
MTP01 (S_1)	45.75^{ab}	10.90^{a}	11.83^{a}	65.06^{a}
CP28 (S_2)	51.33^{ab}	9.62^{b}	8.92^{a}	40.74^{b}
CP29 (S_3)	53.83^{a}	10.56^{a}	11.5^{a}	64.62^{a}
CP30 (S_4)	43.08^{b}	9.16^{b}	9.33^{b}	41.23^{b}
SEm±	2.78	0.32	0.47	4.65
SEd±	3.94	0.45	0.67	6.58
CD (at 5%)	8.04	0.93	1.37	13.45
Soil type				
Laterite soil (ST_1)	42.25^{b}	8.96^{b}	10.33^{a}	35.81^{b}
Black soil (ST_2)	54.75^{a}	11.16^{a}	10.46^{a}	70.02^{a}
SEm±	1.97	0.23	0.33	3.29
SEd±	2.78	0.32	0.47	4.64
CD (at 5%)	5.69	0.67	0.98	9.50
Plant material				
Ramet (P_1)	51.50^{a}	11.67^{a}	10.66^{a}	66.54^{a}
Seedling (P_2)	45.50^{b}	8.46^{b}	10.12^{a}	39.28^{b}
SEm±	1.98	0.21	0.32	3.30
SEd±	2.76	0.33	0.45	4.66
CD (at 5%)	5.70	0.66	0.97	9.51

The number of leaves did not significantly differ between soil types. Ramets exhibited a basal diameter increment of 1.3 mm at 6 MAP. Notably, the interaction between genotype, soil type and plant material significantly influenced all biometric parameters at 6 MAP (Table 5). CP-29 ramet recorded a maximum height of 72.33 cm in black soil. Basal diameter ranges from 15.27 cm to 7.00 cm. The volume index was highest in CP29 ramet in black soil (125.84 cm^3) and lowest in CP30 seedlings in red-laterite soil (21.38 cm^3).

Significant variations among the treatments for ecophysiological traits are represented in Table 6. The net photosynthetic rate (Pn) varied from 7.53 (CP29) to 6.48 μmol/m^2/s (CP30) among the CPTs. It was highest in black soil (7.20 μmol/m^2/s) and lowest in red-laterite soil (6.87 μmol/m^2/s). Ramets recorded more photosynthetic rate (7.92 μmol/m^2/s) than seedlings (6.86 μmol/m^2/s). Likewise, the transpiration rate ranges from 1.61 (MTP01) to 1.52 (CP30) mmol/m^2/s. It was 1.62 mmol/m^2/sin black soil and 1.53 mmol/m^2/s in red-laterite soil. Stomatal conductance among CPTs varied from 0.221 (MTP01) to 0.146 (CP30) mol/m^2/s. It was highest in black soil (0.199 mol/m^2/s), preceded by red laterite soil (0.176 mol/m^2/s). Instantaneous water use efficiency and intrinsic water use efficiency among the CPTs ranged between 4.638 (CP29) to 4.244 (CP30) μmol/mmol and 45.368 (CP30) to 33.382 (MTP01) μmol/mmol, respectively. Instantaneous water use efficiency was 4.455 and 4.446 μmol/mmolin black and red-laterite soil, respectively. Instantaneous water use efficiency for ramets and seedlings was 4.854 and 4.047 μmol/mmol, respectively, whereas intrinsic water use efficiency for ramets and seedlings was 37.264 and 39.912 μmol/mmol, respectively.

Among the CPTs, the ranges of parameters like chlorophyll a varied from 1.598 (CP29) to 1.290 (CP30) mg/g, chlorophyll b ranged between 0.663 (MTP01) and 0.353 (CP30) mg/g and total chlorophyll was between 2.254 (MTP01) and 1.644 (CP30) mg/g, relative water content differed from 73.67 (MTP01) to 63.24 (CP30) per cent (Table 7). Black soil predominates in chlorophyll a (1.475 mg/g), chlorophyll b (0.536 mg/g), total chlorophyll (2.011 mg/g) and relative water content (70.8%) as compared to red-laterite soil. Chlorophyll a, chlorophyll b, total chlorophyll and relative water content in

Table 5. Interaction of soil type, genotypes and propagation technique

Genotype	Height (cm)				Basal diameter (mm)				Number of leaves (No.)				Volume index (cm^3)			
	Black soil		Red laterite soil		Black soil		Red laterite soil		Black soil		Red laterite soil		Black soil		Red laterite soil	
	Ramet	Seedling	Ramet	Seedling	Ramet	Reedling	Ramet	Seedling	Ramet	Seedling	Ramet	Seedling	Ramet	Seedling	Ramet	Seedling
MTP01	67.67	49.00	36.67	39.00	14.5	9.12	11.11	9.23	11.00	13.00	11.67	11.67	98.14	60.47	56.89	38.68
CP28	50.00	46.67	39.00	39.00	11.8	8.34	9.36	9.00	7..67	8.67	9.34	8.67	66.51	33.35	33.56	29.57
CP29	72.33	54.00	39.00	44.67	15.27	9.12	10.27	7.67	14.34	9.34	12.00	10.34	125.84	62.28	46.56	23.77
CP30	56.67	41.67	41.34	43.34	13.31	8.23	8.12	7.00	8.34	10.34	10.34	8.34	74.88	38.68	29.96	21.38
SEm±	5.57				0.64				0.95				9.32			
SEd±	7.88				0.92				1.34				13.17			
CD	16.09				1.87				2.75				26.90			

Table 6. Ecophysiological parameters of all the treatments

Treatments	Photosynthetic rate (µmol/m^2/s)	Transpiration rate (mmol/m^2/s)	Stomatal conductance (mol/m^2/s)	Instantaneous water use efficiency (µmol/mmol^{-1})	Intrinsic water use efficiency (µmol/mmol^{-1})
Sources					
MTP01 (S_1)	7.36^{a}	1.61^{a}	0.221^{a}	4.558^{a}	33.382^{c}
CP28 (S_2)	6.78^{b}	1.55^{a}	0.169^{b}	4.361^{b}	40.223^{b}
CP29 (S_3)	7.53^{a}	1.62^{a}	0.214^{a}	4.638^{a}	35.380^{c}
CP30 (S_4)	6.48^{c}	1.52^{b}	0.146^{c}	4.244^{b}	45.368^{a}
SEm±	0.09	0.01	0.004	0.054	1.17
SEd±	0.12	0.02	0.005	0.077	1.67
CD (at 5%)	0.26	0.03	0.001	0.157	3.41
Soil type					
Laterite soil (ST_1)	6.87^{b}	1.53^{b}	0.176^{b}	4.446^{a}	40.143^{a}
Black soil (ST_2)	7.20^{a}	1.62^{a}	0.199^{a}	4.455^{a}	37.033^{b}
SEm±	0.06	0.007	0.002	0.038	0.83
SEd±	0.09	0.01	0.004	0.054	1.16
CD (at 5%)	0.18	0.02	0.008	0.111	2.41
Plant material					
Ramet (P_1)	7.92^{a}	1.63^{a}	0.205^{a}	4.854^{a}	37.264^{b}
Seedling (P_2)	6.86^{b}	1.52^{b}	0.170^{b}	4.047^{b}	39.912^{a}
SEm±	0.06	0.008	0.003	0.041	0.84
SEd±	0.10	0.02	0.004	0.056	1.18
CD (at 5%)	0.19	0.03	0.008	0.112	2.40

Table 7. Chlorophyll contents and relative water content among the treatments

Treatments	Chlorophyll a (mg/g)	Chlorophyll b (mg/g)	Total chlorophyll (mg/g)	Relative water content (%)
Sources				
MTP01 (S_1)	1.591^{a}	0.663^{a}	2.254^{a}	73.21^{a}
CP28 (S_2)	1.360^{b}	0.372^{b}	1.733^{b}	64.77^{b}
CP29 (S_3)	1.598^{a}	0.645^{a}	2.243^{a}	73.67^{a}
CP30 (S_4)	1.290^{c}	0.353^{b}	1.644^{c}	63.24^{b}
SEm±	0.018	0.015	0.029	0.68
SEd±	0.026	0.021	0.041	0.96
CD (at 5%)	0.054	0.044	0.083	1.97
Soil type				
Laterite soil (ST_1)	1.445^{a}	0.481^{b}	1.926^{b}	66.65^{b}
Black soil (ST_2)	1.475^{a}	0.536^{a}	2.011^{a}	70.80^{a}
SEm±	0.013	0.011	0.02	0.48
SEd±	0.020	0.015	0.03	0.69
CD (at 5%)	0.040	0.031	0.06	1.40
Plant material				
Ramet (P_1)	1.499^{a}	0.534^{a}	2.033^{a}	69.86^{a}
Seedling (P_2)	1.421^{b}	0.482^{b}	1.903^{b}	67.59^{b}
SEm±	0.014	0.010	0.019	0.49
SEd±	0.019	0.014	0.028	0.68
CD (at 5%)	0.038	0.032	0.059	1.38

ramets were 1.499 mg/g, 0.534 mg/g, 2.033 mg/gand 69.86%, respectively.

Relationship between the attributes

Correlation analysis documented in Fig. 1 showed that volume index strongly correlates with height (0.96) and number of leaves (0.99). In contrast, it significantly negatively correlated with water use efficiency (-0.28) and total chlorophyll (-0.09). Similarly, the photosynthetic rate correlated considerably with stomatal conductance (0.75) and the number of leaves (0.68). Height and number of leaves revealed a substantial positive relationship (0.92). Stomatal conductance had a significant positive correlation with the number of leaves (0.93), photosynthetic rate (0.75) and transpiration rate (0.68), while it had a significant negative correlation with water use efficiency (-0.08). The number of leaves (-0.22) and relative water content (-0.3) were found to have a significant negative correlation with total chlorophyll.

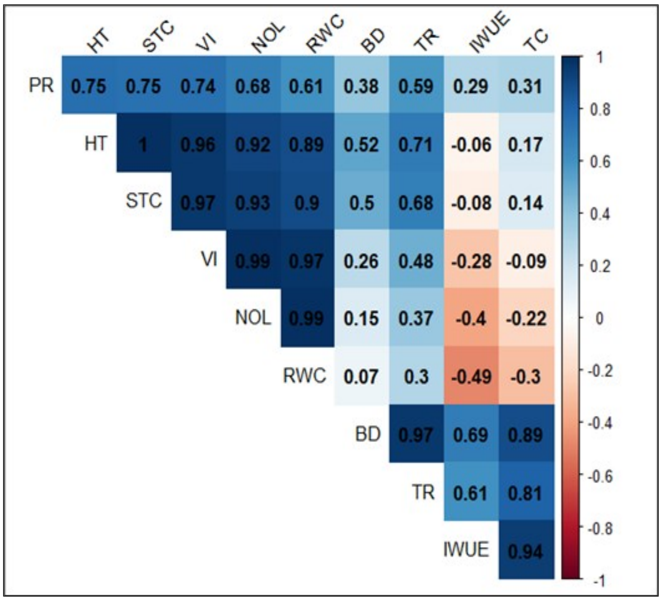

Fig. 1. Correlation analysis among growth traits and physiological parameters of Kapok sources. HT-Height, BD-Basal diameter, VI-volume index, NOL-Number of leaves, TC-Total chlorophyll, RWC-Relative water content, PR-Net photosynthetic rate, TR-Transpiration rate, SC-Stomatal conductance and WUE-Instantaneous water use efficiency.

Principal component analysis

Principal Component Analysis (PCA) was performed to investigate the interrelationships among various components and to evaluate their contributions to the total variation (Table 8). The results indicated that the first principal component (PC1) had an eigenvalue more significant than one, while the second principal component (PC2) had an eigenvalue less than one. PC1 accounted for 59.7% of the total variability and PC2 accounted for 35.1% (Fig. 2). Consequently, the first two principal components explained a substantial portion of the overall variability. In PC1, the highest factor loadings were observed for TC and TR, followed by RWC, PR, IWUE and VI. In contrast, the variability in PC2 was almost equally distributed among all parameters.

Discussion

Newly transplanted germinants or ramets are particularly susceptible to biotic and abiotic stresses, more so than at other life stages. These young plants are fully exposed to the near-surface climate at the whole plant level, lacking the height or branch complexity to mitigate surface environmental effects (17). Consequently, plant physiological ecology is influenced at the whole plant level, emphasizing the importance of studying these dynamics under diverse soil conditions. This study examines kapok seedlings and ramets' growth and physiological traits in black and red laterite soils. This study aimed to systematically measure biometric attributes, photosynthetic gas exchange and chlorophyll parameters; to correlate photosynthetic and biochemical characteristics with growth; and to provide an approach for the rapid evaluation of kapok

Table 8. Proportion of total variability among Ceiba pentandra progenies explained by principal component analysis and the contributions of various traits to the total variability in the principal component

	PC1	PC2
Eigenvalue	8.9	0.9
Percentage of variance	59.7	35.1
Parameters	**Contribution**	
HT (cm)	0.446	0.050
BD (mm)	0.977	0.110
Number of leaves (no.)	0.948	0.106
VI (cm3)	0.979	0.110
PR (μmol/m²/s)	0.992	0.111
TR (mmol/m²/s)	0.996	0.112
STC (mol/m²/s)	0.990	0.111
IWUE (μmol/mmol)	0.985	0.110
TC (mg/g)	0.996	0.112
RWC (%)	.995	0.112

*HT-Height, BD-Basal diameter, VI-volume index, NOL-Number of leaves, TC-Total chlorophyll, RWC-Relative water content, PR-Net photosynthetic rate, TR-Transpiration rate, STC-Stomatal conductance and IWUE-Instantaneous water use efficiency

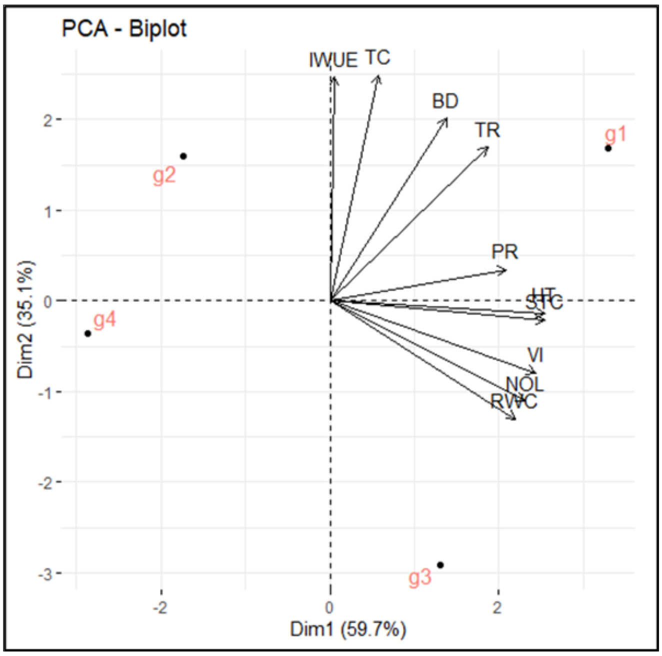

Fig. 2. PCA biplot analysis for Ceiba pentandra sources. HT-Height, BD-Basal diameter, VI- volume index, NOL-Number of leaves, TC-Total chlorophyll, RWC-Relative water content, PR-Net Photosynthetic rate, TR-Transpiration rate, SC-Stomatal conductance and WUE-Instantaneous water use efficiency.

propagated both sexually by seed and asexually by cleft grafting to introduce, utilize and to improve kapok resources in forthcoming breeding plans. Growth attributes, including height and basal diameter, varied significantly depending on soil type, plant source and propagation technique. Height growth is directly associated with site quality. Soil type did affect plant growth and survival (18). The survival rate, plant height, basal diameter and volume index were more significant in black soil than red-laterite soil. This difference could be due to the improved physical and chemical properties recorded in black soil (Table 1). A similar result was documented in the growth performance of mahogany, which was found to be greater in black soil than in red soil in the hilly zone of the northern region of Karnataka (19). Clonal growth is the primary mode of asexual reproduction in vascular plants, playing a crucial role in population expansion and sustaining the population when seedling recruitment is challenging. Ramets exhibited superior plant height compared to seedlings at 3 months after planting (MAP) and 6 months after planting (6 MAP). Clonal plants achieved early, uniform and high yields (20). Of four genotypes, CP-29 ramet recorded the highest height in black soil. Thus, the volume index was reported to be the highest in CP29, while the lowest value was observed in CP30 seedlings in red-laterite soil.

Photosynthesis is the process by which photosynthetic organisms harness solar energy to assimilate atmospheric CO_2, converting it into soluble carbohydrates that are subsequently used for plant growth (21). Photosynthesis is a crucial metabolic process in plants and is a sensitive indicator of changes in the external environment (22). Photosynthetic activity in plants is influenced by a complex interplay of genetic and environmental factors (23). The photosynthetic rate was highest in CP29, indicating that this source demonstrates greater productivity in terms of biomass. The global-scale impact of soil on photosynthetic traits and rates was studied (24). Among the two soil types, the photosynthetic rate was recorded as the maximum in black soil. Mean stomatal conductance for CO_2 (gs) reflects the degree of stomatal opening (25). Stomatal conductance ranged from 0.221 to 0.146. Lower stomatal conductance than the current investigation was documented in *Ceiba pentandra* (26). The transpiration rate was more significant in black soil and highest for CP29 (1.62 mmol/m^2/s). Other such investigations in *Ceiba speciose* support the present study (27).

Water use efficiency (WUE) may be valuable for selecting genotypes with enhanced drought adaptation and biomass productivity under various environmental conditions. At the leaf level, water use is influenced by the available energy impinging on the leaf, vapour pressure deficit and aerodynamic exchange. However, it is regulated by stomatal conductance (gs). Instantaneous water use efficiency was documented to be highest for CP29, signifying its superior ability to divert water for photosynthesis, whereas the lowest efficiency was recorded for CP30. Long-term structural and growth adjustments and changes in intrinsic water use efficiency (WUE) are key mechanisms enabling plants to withstand water limitations. The highest iWUE value was reported more under red-laterite soil than black soil, indicating higher productivity under drought stress. The findings corroborate with *Ceiba pentandra*, *Ceiba glaziovii* and *Eucalyptus* clones (28-30).

The chlorophyll family is essential for harvesting and absorbing light at various wavelengths. This ability enables photosynthetic organisms to adapt to diverse environments over extended periods and during temporary changes in light conditions (31). The present study indicated that chlorophyll a, b and total chlorophyll displayed significantly comparable values across the four sources, soil types and propagation techniques. The highest value was noted in the CP29 source. The chlorophyll content value was 0.61 mg/g in *Ceiba pentandra* seedlings (32). Leaf relative water content (RWC) is a key indicator of plant water status, representing the equilibrium between the water supply to leaf tissues and the transpiration rate (33). The four sources' relative water content was more than 50%, indicating strong drought tolerance. The results are consistent with those observed in *Ceiba pentandra* and teak (34, 35, 36).

Correlation analysis revealed a weak association between water use efficiency (WUE) and stomatal conductance, suggesting that WUE may decrease when stomatal conductance is high. Significant correlations between growth attributes and physiological traits were documented in the current study. There is a positive correlation between photosynthetic rate, number of leaves and stomatal conductance. The research identified a strong positive linear correlation between photosynthetic rate and stomatal conductance in Turkish red pine (37). Similar conclusions and associations were also noted in species like Salix, dipterocarp, Banksia, teak and rubber (38-42). Principal Component Analysis (PCA) is a statistical technique employed to restructure and simplify complex systems characterized by numerous original variables. This is achieved by generating new variables, known as "principal components," which effectively capture the essential information from the original dataset. The Principal Component (PC) score plot for various *Bombax ceiba* species demonstrated 100% total explained variance, indicating the full extent of morphological variation among these species (43). The research shows that in assessing stem dieback disease resistance in *Ceiba pentandra*, Principal Component Analysis (PCA) revealed that the first two principal components accounted for 67.15% of the total variation observed among accessions. Diaspores of different tree species in Brazil were collected and PCA analysis was performed. The two principal components of the PCA analysis (axes 1 and 2) explained more than 80% of the variation included in the matrix of the germination and emergence measurements studied (45). In a principal component analysis (PCA) of *Ceiba pentandra* based on morphological traits, the first two principal components together explained 76.6% of the total variance observed. Specifically, the first principal component accounted for 62.8% of this variation, while the second component contributed 14.1% (46). A principal component analysis (PCA) on *Ceiba aesculifolia* seeds during germination showed that the first component explained 66% of the variation in Relative Water Content, with the second accounting for 13% (47).

Conclusion

A comprehensive understanding of seedlings and ramets cultivated under varying soil conditions is essential for successful establishment and future plantation programs. This study demonstrated that ramets exhibited superior biometric and physiological traits when grown in black soil. Among the four genotypes examined, the CP29 ramet achieved the most significant height in black soil, resulting in the highest volume index. In contrast, the CP30 seedling in red-laterite soil had the lowest volume index. The relative water content for all four sources exceeded 50%. Principal Component Analysis (PCA) indicated that the variance explained was over 94%, with PC1 accounting for 59.7% and PC2 for 35.1%. Factor loadings showed that all the traits studied contributed to the species' variance. Consequently, ramets established through cleft grafting in black soil are conducive to the growth of *Ceiba pentandra* in Tamil Nadu, Southern India. Based on growth traits, the CP29 and MTP01 sources are recommended for further research and plantation initiatives.

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Authors' contributions

RB collected plant materials and established research trials, collected the data, took physiological records and drafted the manuscript. MM helped establish the trial and soil sample collection. KV, NY and BR assisted in the studys' design and helped in the statistical analysis. KBS, IS, and JB provided interpretations and an appraisal of the study.

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

Ethical issues: None

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