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RESEARCH ARTICLE

Evaluation of morphological and anatomical variability in tossa jute (*Corchorus olitorius* L.) genotypes for fiber yield improvement

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Abstract

Tossa jute (*Corchorus olitorius* L.) is a natural fibre crop that produces good quality golden fibre. Predicting fibre yield and quality is crucial in jute breeding programs. Fibre anatomical characteristics provide valuable insights into both fibre yield and quality. Hence, seven tossa jute genotypes were investigated through field-based morphological studies and laboratory-oriented anatomical studies for fibre yield and yield-attributing morpho-anatomical variability at Bangladesh Jute Research Institute (BJRI) during March 2023 to February 2024. Morphological analysis revealed significant genotypic variations in plant height, base diameter, green weight, fibre yield and stick yield ($p < 0.05$), highlighting their potential as key differentiators for breeding activities. The genotypes JRO-524 and O-0412-9-4 exhibited superior traits, including higher plant height (2.67 m and 2.64 m) and base diameter (13.89 mm and 13.18 mm) at 110 days after sowing. High heritability was observed for green weight (80.22 %) and fibre yield (80.05 %), indicating that these traits can be effectively targeted for genetic improvement. Anatomical studies revealed significant variability in stem diameter, bark thickness and fibre bundle attributes ($p < 0.01$). JRO-524 demonstrated the highest stem diameter (17.67 mm) and bark thickness (1.53 mm), while BJRI Tossa pat 9 excelled in trapezoid width and total bundle area. Principal component analysis (PCA) captured 85.7 % of cumulative variance across the first three components, with plant height, base diameter and fibre yield being major contributors. The PCA biplot categorized genotypes into five groups, elucidating genetic diversity for targeted breeding strategies. These findings will provide a foundation for developing high-yielding, fibre-rich tossa jute varieties in future.

Keywords: *Corchorus olitorius* L.; genetic analysis; heritability; jute stem anatomy; trait association

Introduction

Globally, jute is the second most important natural fibre crop following cotton. Bangladesh, as a leading producer of raw jute (1, 2), outperforms other Southeast Asian countries in jute production (3). With 80–85 % of production, tossa jute (*Corchorus olitorius* L.) is the most common type of jute grown commercially in Bangladesh (4). Tossa jute is more susceptible to stress than white jute, although it typically has a higher yield and superior quality (5). Self-pollination and sexual incompatibility, however, limit genetic variation and interchange between these two species (6, 7). The decreased genetic diversity among jute species poses serious problems for jute breeders. It becomes extremely difficult to improve jute varieties under such limitations, especially when it comes to meeting the rising demands of an expanding population. Furthermore, the uncertainties brought about by climate change underscore the importance of preserving genetic variations, as they may include features that make an individual resilient to biotic and abiotic stresses.

In order to investigate heterosis and transgressive segregation in jute, genetic diversity is an essential starting point (8). The development of new commercial varieties and overcoming shortcomings in current ones depends on genotypes with higher genetic diversity (3). Therefore, the primary objectives of jute development initiatives are to identify genetically diversified lines and utilise them efficiently. Both conventional breeding methods, such as hybridization and more recent strategies, like marker-assisted selection, are supported by the identification of jute germplasm with increased genetic diversity (9).

Higher fibre production is not always the result of a wider bark diameter alone. Several anatomical characteristics, such as bark thickness, trapezoid area, the number of trapezoids per unit transverse section, the number of fibre bundle layers per trapezoid and the number of fibre per trapezoid, affect fibre compactness, which in turn affects fibre yield (10). The primary focus of jute production is the fibre, which is composed of secondary phloem cells that are systematically arranged within the fibre wedge. Fibre yield is therefore directly impacted by bark thickness, size & number of trapezoids in the jute stem. Compactness has a significant impact on fibre yield, whereas chemical and physical characteristics influence fibre quality (11).

Substantial morphological and anatomical divergence exists among tossa jute genotypes, with specific phenotypic and anatomical parameters exhibiting significant positive correlations with fibre yield. The strategic selection of genotypes exhibiting advantageous trait combinations holds potential for enhancing genetic gain and facilitating the development of high-yielding cultivars (12). Therefore, seven tossa jute genotypes were evaluated to assess their morpho-anatomical distinctness about fibre yield, to support varietal development. The hypothesis is that genotypes exhibiting distinct morpho-anatomical traits will demonstrate superior fibre yield and can be identified as potential candidates for varietal improvement.

Materials and Methods

Location and timing of the experiment

Jute plants were grown in the field of Jute Agriculture Experimental Station (JAES) of Bangladesh Jute Research Institute (BJRI) located at Manikganj, Bangladesh [23°52′56.1″N 90°01′53.0″E]. The jute stem anatomical studies were done at the anatomical laboratory of the Breeding Division of BJRI, Dhaka [23°45′26 N, 90°22′47 E], Bangladesh. The full study, including the growing of plants to seed collection, was conducted from March 2023 to February 2024.

Plant materials

A total of seven tossa jute genotypes, including two breeding lines, one accession and four varieties, were used in this study (Table 1). Seeds were sourced from the Genebank Department and Breeding Division of BJRI in 2023.

Experimental design, seeding and plants growing

The experiment was conducted using a randomised complete block design with three replications for each genotype, with a line-to-line spacing of 30 cm and a unit plot size of 2.1 m by 1 m.

Morphological data collection

For each replication, ten randomly selected competitive plants were considered for each genotype at 110 days after sowing to collect data on the following characters. Plant height was obtained by measuring the length of the plants from the base to the tip of the last leaf using a meter scale from 10 randomly selected plants and then averaging. Each genotype's base diameter was measured with digital slide callipers in each replication and the average was computed. To prevent weight loss from desiccation, plants were weighed as soon as they were harvested. With the aid of an electronic weighing balance, the fresh weight of plants in the plot was determined for each genotype.

The extracted fibres were cleaned, adequately sun-dried and weighed (g) following proper retting. The average dry fibre weight per plant was calculated.

Following the removal of the fibre from the plants, the stick was weighed (g) for each genotype using the weighing balance.

$$\text{Average value of the parameter} = \frac{\sum value\ of\ total\ plants}{number\ of\ total\ plants} \quad \text{(Eqn. 1)}$$

The fibre yield (FY) and stick yield (SY) in ton/ha were calculated by converting the values that have been found in 2 m^2 plot into 1 ha (Eq. 2 & 3).

$$\text{FY*(ton/ha)} = \frac{\sum Fiber\ yield\ per\ plot(kg) * 10000m2}{unit\ plot\ size(2m2) * 1000} \quad \text{(Eqn. 2)}$$

$$\text{SY*(ton/ha)} = \frac{\sum Stick\ yield\ per\ plot(kg) * 10000m2}{unit\ plot\ size(2m2) * 1000} \quad \text{(Eqn. 3)}$$

Anatomical study

The experimental jute plants reached physiological maturity around 110-120 days, which allowed for both fibre production and anatomical analysis (13). Using a jute harvesting knife made to prevent damage, three plants, each 110 days old, were selected at random from the middle row of each genotype for anatomical research. A simple and rapid process was used for jute anatomy, based on the approach described by (14). Using a sharp knife, 3-4 cm long segments of jute stems that had both fibre (phloem) and stick (xylem) were cut from around 4-5 cm above the base of each plant. The collected jute anatomical samples were kept in a solution of Formalin-Aceto-Alcohol (FAA) (10 mL of Formalin, 5 mL of 85 % glacial acetic acid and 85 mL of 70 % alcohol). To prepare the slide, transverse sections (T.S.) of around 20-25 mm thickness were cut using a microtome. According to the previous works, stem diameter, bark thickness, number and area of trapezoids, number of fibre bundles per layer and number of fibre bundles per section (Fig. 1) were all measured while the slides were examined under a compound microscope with 4×10 magnifications as shown in equations 4 and 5 (14, 15).

Area of trapezoid (sqmm) = 1/2 (upper length + Lower length) × perpendicular length of trapezoid × conversion factor.

[Conversion factor = 39.4 in 4 x 10 magnification] (Eqn. 4)

Total bundle area transverse per section (sqmm) = Total number of trapezoid transverse/section × Area of trapezoid (Eqn. 5)

Statistical analyses

Anatomical and morphological information was carefully collected and arranged using Microsoft Excel (MS Office 2016). Tukey's tests, correlation coefficients, analysis of variance, descriptive analyses were carried out with Minitab statistical package (Minitab 19.2.0). Genetic analysis was done with the help of 'R' statistical package (R 4.3.1).

Table 1. List of plant materials with their development process, plant type and country of origin

Genotypes	Development process	Plant type	Country of origin
G1- O-0512-6-2	BJRI Tossa pat 5 × O-4	True breeding line	Bangladesh
G2- O-0412-9-4	JRO-524 × A-4582	True breeding line	Bangladesh
G3- Acc. 4582	Pure line selection (PLS)	Accession	Bangladesh
G4- BJRI Tossa pat 5	Uganda red × O-4	Pre-released variety	Bangladesh
G4- BJRI Tossa pat 8	PLS of mutants	Pre-released variety	Bangladesh
G6- BJRI Tossa pat 9	JRO-524× Acc. 1749	Pre-released variety	Bangladesh
G7- JRO-524	African (cv. Sudan Green) × indigenous (cv. JRO-632)	Pre-released variety	India

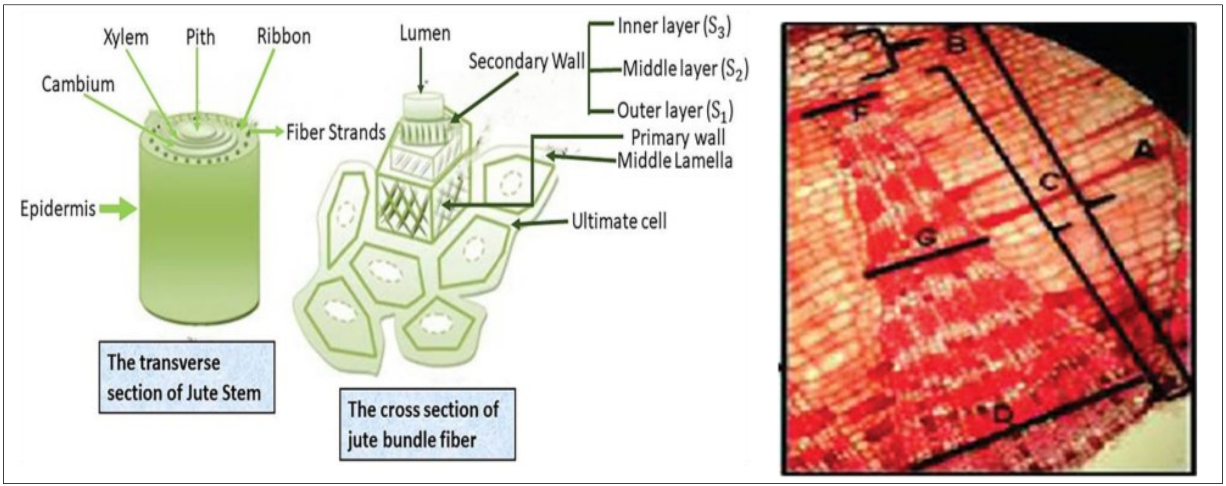

Fig. 1. A. The overall thickness of the bark; **B.** The distinction between the fibre wedge tip and the epidermis; **C.** The trapezoid's average length and height; **D.** The trapezoid's average base width; **E.** Middle trapezoid's average width; **F.** The average width of the top trapezoid; **G.** Schlerenchyma cell; **H.** Cambium layer and **I.** Vacuole (14, 15).

Results

Morphological study

Morphological variability

According to statistical studies, the genotype mean square values for base diameter, dry fibre yield, dry stick yield and green weight with leaves showed significant differences, indicating that these factors were the primary differentiators among the genotypes. Significant differences ($p < 0.05$) were seen in plant height and the ratio of stick yield to fibre (Table 2). These variables can also be taken into account when developing new varieties of tossa jute. A key factor in increasing the jute fibre yield is stem height. The two genotypes with the highest stem heights were O-0412-9-4R (2.64 m) and JRO-524 (2.67 m). In 110 days, the average plant height of BJRI Tossa pat 8 was the lowest at 2.14 m (Table 3). Advanced line O-0412-9-4R provided the largest base diameter (13.89 mm) with the highest fibre content in this study, followed by JRO-524 (13.18 mm). The base diameter of BJRI Tossa pat 9 was the smallest, measuring 11.02 mm (Table 3). Fibrous plant material with a higher stem base diameter increases fibre yield and may be utilized as hybridization breeding material (16, 17).

The green weight of the jute plant is correlated with the yield of jute fibre (9). The fresh weight of jute plants has a direct correlation with yield performance (2). The advanced line O-0412 -9-4R (238.96 g) trailed the JRO-524 in this trial with leaves that had a greater fresh weight (268.29 g) (Table 3). BJRI Tossa pat 9 had the opposite effect on base diameter (157.14 g). The fresh weight findings without leaves were nearly identical. Because they shed green leaves, jute genotypes with higher biomass content may be crucial in increasing fibre yield content and improving soil fertility (3).

Table 2. Analysis of variance (MS) for morphological characters of seven tossa jute genotypes

Sources of variation	Genotype	Replication	Error
df	6	2	12
PH (m)	0.11*	0.01213	0.02
BD (mm)	3.42**	0.09396	0.35
GLW (g /plant)	5199.3***	1041.0	395.0
GLW0 (g/plant)	3472.1**	460.5	509.7
FY (g / plant)	43.71**	0.7898	3.35
SY (g / plant)	225.82**	8.267	22.12
FY* (ton/ha)	0.88*	0.4046	0.29
SY* (ton/ha)	6.848**	1.497	1.02
SY:FY (SFR)	0.33*	0.1194	0.09

Note: df- Degrees of freedom, PH-Plant height (m), BD- Base diameter (mm), GWL-Green weight (g) with leaves/plant, GWL0-Green weight without leaves/plant, FY-Dry fibre yield g/plant, FY*-Dry fibre yield (t/ha), SY-Dry stick yield g/plant, SY*-Dry stick yield (t/ha), SFR-Ratio between fibre and stick yield; *, ** and *** indicate significant at 0.05, 0.01 and 0.001 levels of probability; ns indicate non- significant

Fibre is the primary desired characteristic of jute plants (14). JRO-524 had the highest fibre yield (18.43 g/plant, 3.05 t/ha) among the six genotypes, followed by advanced line O-0412-9-4R, etc. (Table 3). Genotypes with good fibre yield content could be improved through breeding techniques and further cultivated for the next generation to develop high-yielding new tossa jute varieties, like to cotton breeding (18). Stick yield varied significantly among the genotypes, ranging from 24.09 g/plant (G5) to 44.72 g/plant (G2). The highest stick yield per hectare was recorded in G7 (8.15 t/ha), followed by G3 (7.65 t/ha) and G2 (7.59 t/ha), while the lowest was observed in G5 (4.22 t/ha).

Table 3. Mean performance of seven genotypes for yield and yield attributing morphological characters

Gen	PH	BD	GLW (g/plant)	GLW0 (g/plant)	FY (g/plant)	SY (g/plant)	FY* (ton/ha)	SY* (ton/ha)	SFR
G1	2.35^{ab}	11.33^{b}	168.79^{bc}	120.15^{b}	11.94^{b}	27.98^{bc}	2.23^{ab}	5.69^{abc}	2.36^{ab}
G2	2.64^{a}	13.89^{a}	238.96^{a}	138.30^{b}	18.85^{a}	44.72^{a}	2.60^{ab}	7.59^{ab}	2.38^{ab}
G3	2.44^{ab}	13.45^{a}	217.23^{ab}	136.66^{b}	13.75^{ab}	39.51^{ab}	2.65^{ab}	7.65^{ab}	2.88^{a}
G4	2.58^{ab}	12.63^{ab}	211.78^{abc}	161.52^{ab}	17.45^{a}	34.75^{abc}	2.59^{ab}	5.22^{bc}	2.0^{b}
G5	2.14^{b}	12.61^{ab}	166.96^{bc}	144.06^{b}	11.87^{b}	24.09^{c}	2.07^{ab}	4.22^{c}	2.04^{ab}
G6	2.36^{ab}	11.02^{b}	157.14^{c}	101.52^{b}	8.98^{b}	25.05^{c}	1.9^{b}	5.34^{abc}	2.74^{a}
G7	2.67^{a}	13.18^{a}	268.29^{a}	208.64^{a}	18.43^{a}	43.56^{a}	3.5^{a}	8.15^{a}	2.38^{ab}

Note: PH-Plant height (m), BD- Base diameter (mm), GWL-Green weight (g) with leaves/plant, GWL0-Green weight without leaves/plant, FY-Dry fibre yield g/plant, FY*- Dry fibre yield (t/ha), SY-Dry stick yield g/plant, SY*-Dry stick yield (t/ha), SFR-Ratio between fibre and stick yield

Genetic analysis of morphological traits

In this study, heritability in the broad sense varied from 41.11 % for fibre yield (t/ha) to 80.22 % for green weight (g) with leaves plant. The heritability of tossa jute was shown to be high in terms of base diameter, green weight, fibre yield and stick yield, whereas it was moderate in terms of plant height and the stick-to-fibre ratio (19) (Table 4). To manage breeding objectives through hybridization, breeders should possess a thorough understanding of the heritability of desirable traits in jute crops (4, 9). The highest genetic advance was found in fresh weight with leaves/plant (73.83 g) and the lowest in the plant height (0.24 m) (Table 4). The genetic advance in per cent of mean (GAM %) for tossa jute plant height and fibre yield/plant varied from 10.16 % to 46.72 %. The GAM % was moderate for plant height, base diameter and the fibre yield-stick yield ratio, but it was high for green weight, fibre and stick yield (Table 4).

Anatomical study

Anatomical variability

Variability among the genotypes was found by the analysis of variance for the anatomical analysis of seven tossa jute genotypes (Table 5). Variations were found to be highly significant ($p < 0.1$) for anatomical features, such as stem diameter, bark thickness, trapezoid height and width, total bundle area/section and number of bundle layers/trapezoid (Table 5).

Anatomy of jute stem (T.S.)

The genotypes of jute exhibited statistically significant differences in anatomical features that were linked to fibre output. Among the jute plant's anatomical characteristics, JRO-524 had the highest results for stem diameter (17.67 mm), bark thickness (1.53 mm), bundle layer/trapezoid (12), average number of trapezoid/T.S. (90.67) and height of trapezoid (1.41 mm) (Fig. 2). BJRI Tossa pat 9 had the highest number of trapezoid/T.S. (66), average width of trapezoid (0.686 mm) and total bundle area/section (44.29 mm^2) (Table 6). Regarding these anatomical characteristics, the other genotypes, such as Acc. 4582, BJRI Tossa pat 5 and advanced line O-0412-9-4 also shown favourable outcomes. A trapezoid's area is determined by its width and height (5). The highest number of trapezoid per transverse section was found in jute genotypes with larger base diameter and stem height (20, 21). Variations in the fibre bundle area per transverse section (T.S.) between genotypes were highly significant ($p < 0.01$). Inter-varietal variances were found in the fibre bundle of jute crops (22).

Analyses of principal components (PCA) for morpho-anatomical data

For the morphological and anatomical variables under study, principal components were examined to determine genetic variability across all jute genotypes. The Principle Component Analysis (PCA) revealed the most appropriate correlation between the traits under investigation. The biplot's vector length showed the amount of variation explained by each trait of the tossa jute genotypes (Fig. 3). The first three main components in the PCA scree plot analysis (Fig. 4) have eigenvalues > 1.0, which explains 85.7 % of the cumulative variance. Of the total variances in PCA, the first component had 43.5 %, the second had 32.2 %, the third had 10.1 %, the fourth had 9.1 % and the fifth had 3.5 % (Table 7).

Table 4. Genetic analyses for studied morphological traits

Characters	GV (σ^2_G)	PV (σ^2_P)	GCV (%)	PCV (%)	ECV (%)	h^2_{bs} (%)	GA	GAM (%)
PH	0.03	0.05	6.77	9.28	6.35	53.18	0.25	10.17
BD	1.02	1.37	8.03	9.31	4.71	74.40	1.80	14.27
GLW(g/plant)	1601.46	1996.42	19.60	21.88	9.73	80.22	73.83	36.16
GLW0(g/plant)	987.47	1497.17	21.76	26.79	15.63	65.96	52.57	36.40
FY(g/plant)	13.45	16.80	25.35	28.33	12.66	80.05	6.76	46.72
SY(g/plant)	67.90	90.02	24.07	27.71	13.74	75.43	14.74	43.06
FY*(ton/ha)	0.20	0.49	17.71	27.61	21.19	41.11	0.59	23.39
SY*(ton/ha)	1.94	2.96	22.22	27.45	16.13	65.47	2.32	37.03
SFR	0.08	0.17	11.66	17.23	12.69	45.76	0.39	16.24

Note: Genetic variance (GV) (σ^2G), phenotypic variance (PV) (σ^2P), genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), environmental covariance (ECV) and general heritability (h^2bs) Genetic advance (GA) and genetic advance (GAM) as a percentage of the mean; PH ~ SFR

Table 5. Analysis of variances (Mean square values) for anatomical characters

DF	SD (mm)	BT (mm)	BLT	FBT	TS	WT(mm)	HT(mm)	TBAS(sqmm)
Genotype	9.22***	1.014^{***}	7.429^{**}	665.5^{*}	117.97^{*}	0.05**	0.087***	253.46**
Error	0.226	0.09	1.33	224.8	40.00	0.01	0.01	55.46

Note: SD- Stem diameter (mm), BT- Bark thickness (mm), BLT- No. of Bundle layer $trapezoid^{-1}$, FBT- Fibre Bundle/trapezoid, TS- No. of trapezoid transverse $section^{-1}$, WT- Av. width of trapezoid, HT- Height of trapezoid, TBAS- Total bundle area transverse $section^{-1}$; df- degrees of freedom, ** means statistically significant at 0.05 and 0.01 probability level, respectively

Table 6. Mean performance for anatomical features of seven tossa jute genotypes

Gen	SD (mm)	BT (mm)	BLT	FBT	TS	AT (mm)	HT (mm)	TBAS (sqmm)
G1	12.67c	1.280^{b}	10.0^{ab}	56.33ab	47.67b	0.37b	1.19abc	19.11b
G2	14.0b	1.35^{ab}	11.67^{a}	60.33ab	50.33ab	0.39b	1.29ab	19.74b
G3	14.33b	1.16^{bc}	10.67^{ab}	78.0 ab	51.33ab	0.58ab	1.08bc	30.26ab
G4	17a	1.3^{ab}	9.67^{ab}	66.0ab	52.33ab	0.37b	1.23ab	19.89b
G5	14.33b	1.02^{c}	7.67^{b}	47.33b	48.67ab	0.483ab	0.93c	23.66ab
G6	15.0b	1.53^{a}	12.0a	55.33ab	66a	0.686a	1.4a	44.29a
G7	17.67a	1.53^{a}	12.0a	90.67a	49.33ab	0.647ab	1.41a	31.55ab

Note: SD- Stem diameter (mm), BT- Bark thickness (mm), BLT- No. of Bundle layer $trapezoid^{-1}$, FBT- Fibre Bundle $trapezoid^{-1}$, TS- No. of trapezoid transverse $section^{-1}$, WT- Av. width of trapezoid, HT- Height of trapezoid, TBAS- Total bundle area transverse $section^{-1}$

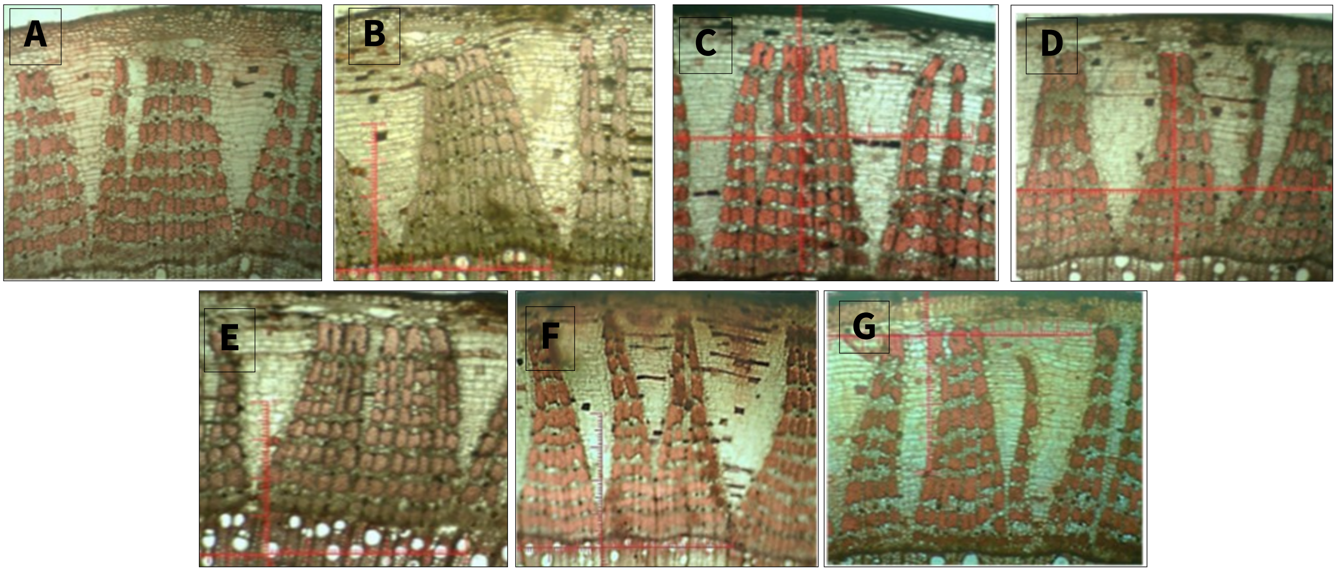

Fig. 2. Fibre anatomy of seven tossa jute genotypes: **a.** O-0512-6-2; **b.** JRO-524; **c.** O-0412-9-4; **d.** BJRI Tossa pat 9; **e.** BJRI Tossa pat 5; **f.** BJRI Tossa pat 8 and **g.** Acc. 4582.

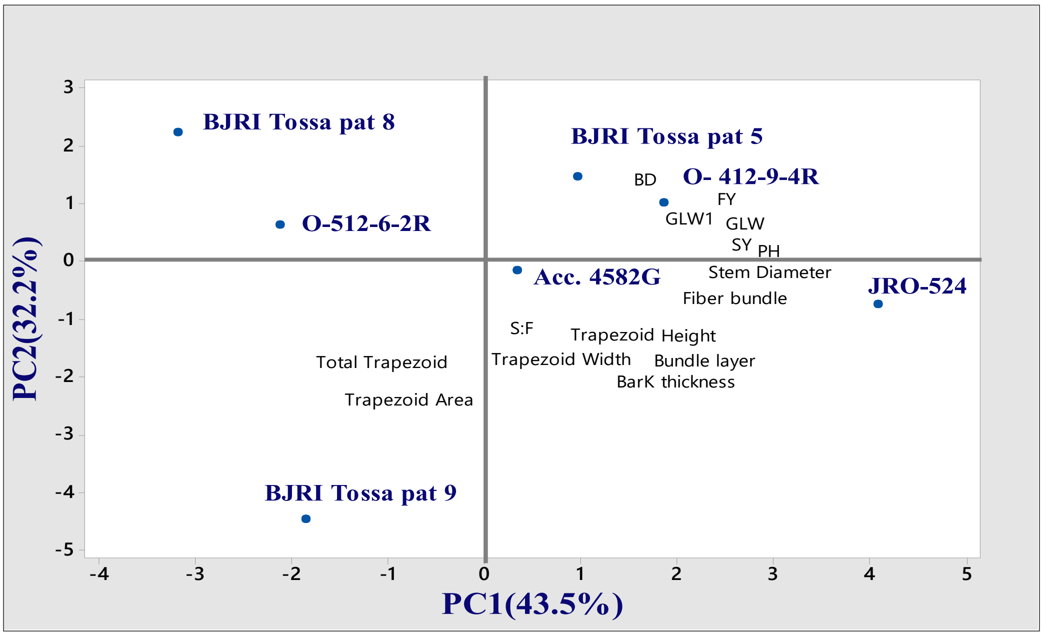

Fig. 3. Biplot in PCA showing relationships among seven tossa jute genotypes for morpho-anatomical traits.

Table 7. Eigenvalues of the covariance matrix

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Eigenvalue	6.5255	4.8248	1.5096	1.3667	0.5315	0.2419	0.0000	0.0000	0.0000	0.0000
Proportion	0.435	0.322	0.101	0.091	0.035	0.016	0.000	0.000	0.000	0.000
Cumulative	0.435	0.757	0.857	0.948	0.984	1.000	1.000	1.000	1.000	1.000

The majority of the variation is captured by the PCA biplot, which effectively reduces the dataset's dimensionality to two principle components. Positive coefficients of plant height, base diameter, green weight with and without leaves/plant, fibre yield/plant, stick yield/plant, stick fibre ratio, stem diameter (mm), bark thickness, bundle layer, number of fibre bundle/ trapezoid, average width of trapezoid (mm) and height of trapezoid (mm) were the main contributors to variation in PC1 (Table 8 & Fig. 4). Additionally, the negative coefficients of total trapezoid/section and size of trapezoid (sqmm) were a major contributor to the variation in PC1 across morpho-anatomical features of seven tossa jute genotypes, as shown in the biplot. The PCA biplot (Fig. 4) divided the seven tossa jute genotypes into five groups. Based on their shared characteristics and locations in several quadrants that were far from the centre, the genotypes were categorized.

Discussion

Morphological studies

Morphological traits that exhibit highly significant variations, such as plant height, fresh weight and fibre yield, should be given priority over traits that exhibit non-significant variations, like the ratio of fibre to stick yield and traits that exhibit significant variations, like base diameter and stick yield content (23). Significant diversity was noted in a number of jute morphological features in previous research (12, 24, 25). The genotypes O-0412-9-4, JRO-524, Acc. 4582 and BJRI Tossa Pat 5 performed well in fibre production. Tossa jute genotypes with greater variability for traits like plant height, fresh weight and fibre yield can act as potential breeding materials for the development of the tossa jute variety (25). Plant height has a direct impact on fibre elongation, which is essential for a high fibre yield in jute (26). JRO-524 and O-

Table 8. Coefficients of principal components for different morpho-anatomical traits of tossa jute genotypes

Variable	PC1	PC2	PC3	PC4
PH	0.369	-0.025	0.078	0.246
BD	0.255	0.227	-0.337	-0.083
GLW	0.379	0.084	-0.112	-0.051
GLW0	0.298	0.150	0.176	-0.391
FY	0.339	0.208	0.072	0.119
SY	0.360	0.071	-0.255	0.128
SFR	0.017	-0.325	-0.547	0.037
SD(mm)	0.229	-0.029	0.485	-0.378
BT(mm)	0.208	-0.328	0.259	0.213
BLT	0.241	-0.318	-0.115	0.282
FBT	0.332	-0.061	-0.157	-0.284
TS	-0.082	-0.395	0.162	0.024
AT(mm)	0.043	-0.359	-0.165	-0.462
HT(mm)	0.222	-0.302	0.264	0.293
TBAS(sqmm)	-0.015	-0.417	-0.059	-0.311

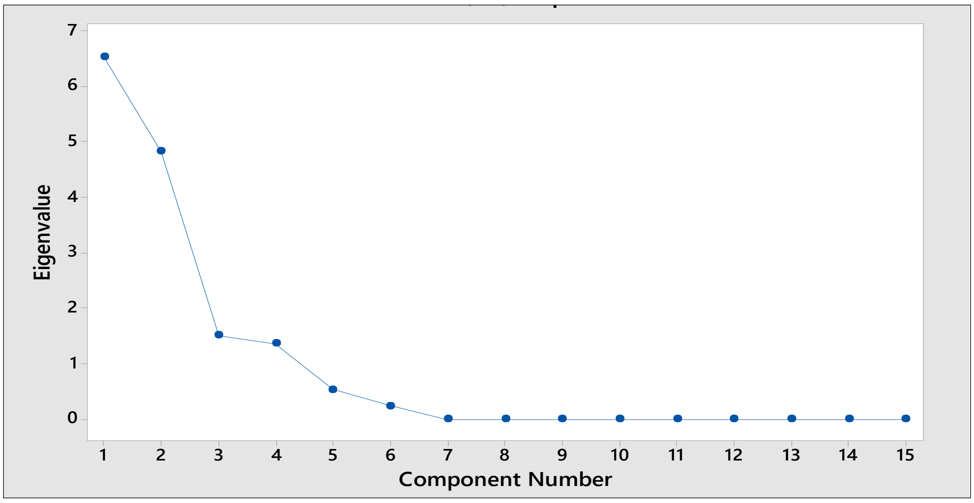

Fig. 4. Scree plot in PCA analysis.

0412-10-4 might be used as breeding material to create a new variety, which had the highest plant height in this study (4). Significant correlations have been found between jute fibre yield, plant height and increasing base diameter is crucial for boosting fibre yield (19). With higher base diameters, genotypes O-0412-10-4, Acc. 4582 and JRO-524 are potential options for hybridization-based varietal improvement. The fibre yield of jute plants is greatly influenced by their green weight, particularly the green stem devoid of leaves and thicker bark (27). Both JRO-524 and BJRI Tossa pat 5 showed promising fresh green fibre weight results and might be used to generate new varieties. In terms of fibre yield content, genotypes O-0412-10-4, JRO-524 and BJRI Tossa pat 5 performed better. Fibre yield is still the major objective for jute crops (28). High-yielding tossa jute varieties can contribute a lot to Bangladesh's national economy (23, 17, 29). In addition, jute sticks have a great use as fuel, ink and cosmetics industry (30). The production of charcoal, automobile desk boards and ink has increased the use of jute sticks (31, 32). For plant breeders to choose suitable parents for breeding programs, they require a thorough grasp of these relationships (33).

Anatomical studies

In jute breeding programs, it is essential to predict fibre yield and quality and a quick evaluation is required (17). Because of the considerable variation in fibre content and fibre bundle structure, which is impacted by retting circumstances, morphological characteristics of jute plants can only marginally suggest fibre output; however, they are less accurate in determining fibre quality. In breeding projects, anatomical studies are infrequently employed, although they provide a rapid and efficient means of evaluating the fibre quality and yield potential of tossa jute (10). Compared to morphological variables, anatomical traits are a better predictor of fibre yield and quality in tossa jute (*Corchorus olitorius* L.) genotypes, according to a quick selection procedure (5). Anatomical characteristics varied significantly amongst jute genotypes, with bark diameter being a major factor in stick and fibre yield (10). Jute fibres are made up of many sclerenchymatous cells.

Based on their high bark diameter performance, genotypes such as BJRI Tossa pat 5, JRO-524, BJRI Tossa pat 9 and O-0412-9-4 were selected in this study as possible breeding parents for tossa jute yield improvement (23). Fibre fineness can be enhanced by using genotypes with thicker bark tissue, thinner cell walls and reduced lignin concentration (34, 35). BJRI Tossa pat 9, JRO-524 and advanced lines like O-0412-9-4, O-0512-6-2 and O-0411-10-4 are among the seven genotypes with thicker barks that can be used as parental material to breed current cultivars with thicker fibres. Advanced lines such as O-0412-9-4, which have greater fibre bundle areas and the genotypes BJRI Tossa pat 5 and JRO-524 are regarded as fine and may be utilized to create new high-yielding cultivars. The quantity of pyramid-shaped trapezoids in a jute stem's transverse section (T.S.) has a direct impact on the fibre cell area and yield (22). Accordingly, the area of the fibre cell grows with the number of trapezoids (36). The number of trapezoids/T.S. was well-performed by genotypes such as BJRI Tossa pat 9, BJRI Tossa pat 5, JRO-524, O-0412-9-4 and Acc. 4582, which might be utilized to enhance the fibre anatomy of existing varieties or newly developed high-yielding varieties. The number of trapezoids, the number of fibre bundle layers/trapezoid and the area of each trapezoid all affect the yield of jute fibre and the total area of the fibre bundle (22, 25). BJRI Tossa Pat 9, JRO-524, Acc. 4582, BJRI Tossa Pat 8 and O-0412-9-4 all performed well in this investigation in terms of these characteristics. The best genotypes for crop improvement and hybridization are those with superior base diameter, bark thickness, trapezoid area, number of trapezoids/T.S., number of fibre bundle layers/trapezoid and total fibre bundle area T.S. (5).

Trait association

Principal component analysis (PCA) has been used extensively for a variety of reasons in jute crop research to analyze trait relationships. The analysis found that the first two principal components (PC1 and PC2) accounted for 99.51 % of the variation, with PC1 accounting for 90.89 % and PC2 for 8.62 %. According to earlier research, the first three components, PC1, PC2 and PC3, are the most helpful in describing the patterns of variation among various jute genotypes (32). The experiment's PCA findings showed how much genotype-specific trait variability exists, which may be used to enhance jute. To target desirable qualities in jute, breeders must analyze genetic indices such as variance, co-variance, broad-sense heritability and genetic advancement (37). A substantial genotypic contribution to phenotypic expression was indicated by the seven jute genotypes under study, where phenotypic coefficients of variation (PCV) were greater than genotypic coefficients of variation (GCV) (2, 9, 37). Traits with high heritability indicate little environmental influence, which facilitates selection through potent additive genetic effects (4, 38). In jute, previous studies have also found high to moderate broad-sense heritability for characteristics such as stick yield per plant, dry fibre yield, fresh weight (with and without leaves), plant height and stem base diameter (7, 19). In the present investigation, characteristics such as fibre yield per plant (80.05 %) and green weight with leaves (80.22 %) showed substantial heritability. Fresh weight with and without leaves had high heritability and genetic advance as a percentage of mean (GAM), but other variables had low GAM and moderate heritability, indicating no additive gene action (4). Selection based on these features may be successful in subsequent generations of plants.

Conclusion

Genotypes O-0412-9-4 and JRO-524 were the superior genotypes among the seven tossa jute genotypes examined in this study. They performed well in both morphological traits (plant height, stem base diameter, plant fresh weight and fibre yield) and anatomical traits (bark diameter, bark thickness, trapezoid area, fibre bundle area and fibre bundle layers/trapezoid). The significant potential of these genotypes for jute crop improvement is highlighted by the observed heterogeneity among them, which is mostly caused by genetic factors influencing both quantitative and qualitative features. Through hybridization and molecular breeding, these genotypes show promise for creating promising tossa jute cultivars. It may be possible to develop these advanced lines as superior varieties through pure line selection in field trials. Additionally, the anatomical analysis eliminates the need for harmful samples and provides a rapid and effective way to screen for particular features in jute genotypes. This work will be beneficial for future jute breeding projects.

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Authors' contributions

NT conceived, designed and performed the experiments, analyzed and interpreted the data, and wrote the manuscript. SSUA supervised the experiment and helped in data collection. MH, SAKH and MMM helped in writing the manuscript and data collection. MMM reviewed the article for data analyses, submitted it to the journal, and handled the communication for publication. All authors contributed to the article and approved the submitted version for publication.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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