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Identification of Elite Parental Lines in White Jute (*Corchorus capsularis* L.) based on Fiber Anatomical Traits and Diallel Hybridization

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Abstract

White jute (*Corchorus capsularis* L.) is an important bast fiber crop, but reliable selection criteria for improved fibre yield and quality remain limited. This study, conducted at the Bangladesh Jute Research Institute (BJRI) in Dhaka, aimed to identify elite parental lines by assessing fiber anatomical properties and diallel hybridization performance. Seven genotypes, comprising five advanced breeding lines and two established varieties (CC-45 and BJRI deshi pat 9), were evaluated at 100 days post-sowing for bark diameter, bark thickness, number of fiber-bundle layers per trapezoid, trapezoid height, and trapezoid area. Significant genotypic differences were apparent for all measured characteristics. Notably, advanced lines C-870 and C-2262 consistently showed better bark development, increased compactness of the fiber bundle and larger trapezoid areas, indicating a strong fiber yield potential. The full diallel mating programme resulted in 48 successful hybridizations out of 95 attempted crosses, giving a total cross-ability of 50.52 percent. The crosses involving C-870 and C-2262 have shown a relatively high success rate, which confirms their efficacy as parental surrogates in hybrid breeding programmes. Combined anatomical superiority and satisfactory hybridization performance confirm C-870 and C-2262 as the elite breeding lines for improving fiber yield and quality in breeding programmes for white jute.

Keywords: Diallel hybridization, Fiber anatomy, Fiber yield, Trapezoid area, White jute

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Introduction

Jute (*Corchorus* spp.) is one of the most important natural bast fiber crops in the world and ranks second only to cotton in terms of worldwide fiber use. Jute has re-emerged as a sustainable alternative to synthetic fibers in various industrial sectors (Rahman et al., 2017) due to its biodegradability, recyclability, low carbon footprint and environmental benefits. It is worth noting that Bangladesh accounts for a significant share of the world's supply of raw jute and products derived from jute (Gupta et al., 2009). Jute is an attractive alternative to synthetic fibers in many industrial applications due to its biodegradability, recyclability, low carbon emissions and environmental performance (Basu and Roy, 2008).

Bangladesh accounts for a significant share of the world's raw jute and jute-derived products (Gupta et al., 2009). Due to its biodegradability, recyclability, low carbon footprint and environmental properties, jute has become a preferred sustainable alternative to synthetic fibers in a wide range of industrial sectors (Basu and Roy, 2008; Rahman et al., 2017). Bangladesh and India together account for more than 85 per cent of the world's jute production, with Bangladesh being the main supplier of both raw fiber and finished products (Gupta et al., 2009). In addition to its economic value, the jute industry promotes employment, strengthens rural communities and promotes environmental sustainability (Islam and Ali, 2017).

Among the species cultivated, *Corchorus capsularis* L. (white jute) is the most widely cultivated because of its ability to thrive in a variety of agro-ecological environments, including floodplains. Unlike *C. olitorius*, white jute has a lower photoperiod sensitivity and a more favorable response to fertilization, which allows it to adapt to a variety of management strategies (Paul, 1993; Rahman et al., 2017). However, improving fiber yield and quality remains a challenge, as these characteristics are polygenic and highly sensitive to environmental changes (Alam et al., 2010; Kumar et al., 2014).

Traditionally, the assessment of fiber yield requires destructive harvesting and replanting, which prevents the plants from being used to produce seeds. Although morphological characteristics such as the height of the plant and the basal diameter are moderately correlated with fiber yield, they are often not sufficient to accurately predict fiber quality (Kumar et al., 2014).

Jute fiber is anatomically composed of secondary phloem cells, which accumulate during growth and are organized in a regularly spaced patch of fibers on the stem (Nawaz et al., 2011; Parvin et al., 2018). The thickness of the bark and the number and area of the phloem segments contribute directly to the fiber yield potential. Jute fiber is not a single fiber, but a commercial multilayer fiber composed of multiple end-wovens. The fiber quality depends largely on the length and the ratio of length to width of these end fibers, which affects the fiber strength, fineness, and spinning performance.

On the other hand, anatomical features related to the development of bast fibers, particularly in the secondary phloem, provide a more reliable and non-destructive method of early selection (Satya et al., 2011). The mast fiber is organized into distinct strands arranged in trapezoidal groups throughout the stem. Parameters such as bark diameter, bark thickness, number of layers of fiber bundle, number of cells per bundle, and trapezoid height and area were found to be strongly correlated with fiber yield and quality (Sengupta and Palit, 2004; Pervin and Haque, 2012).

Hybridization remains the primary approach to integrating positive features of genetically diverse parents. Dialysis mating patterns are often used to assess parental performance, inter-compatibility and mating capacity (Griffing, 1956; Acquaah, 2007). In jute, the effective hybridization is dependent on the synchronization of the flowers and the successful compatibility after pollination (Khatun, 2007). The selection of parental species with better fiber anatomical characteristics and a strong hybridization potential is essential to produce high-yielding, high-quality fiber varieties.

The study was carried out to: (i) assess white jute genotypes based on fiber-related anatomical properties, (ii) identify elite parental lines for increasing fiber yield and (iii) develop promising hybrid combinations using a full diallel mating system to support future breeding efforts in white jute.

Materials and Methods

Experimental Site and Plant Materials

The experiment was conducted at the Bangladesh Jute Research Institute (BJRI) on Manik Mia Avenue in Dhaka. Seven white jute genotypes were evaluated, comprising five advanced breeding lines (C-870, C-2262, C-5002, C-5036, and C-5149) and two popular varieties (C-45 and BJRI deshi pat 9). The seeds were obtained from the BJRI Gene Bank.

Pot Preparation and Crop Management

The genotypes were grown in earthen pots containing soil enriched with cow manure and organic fertilizer. The seedlings were planted according to the recommended planting schedule, and the seedlings were thinned to ensure uniform density of the stands. Standard intercultural practices, such as weeding and irrigation, have been applied where appropriate. Irrigation was applied whenever deterioration was observed to ensure optimum moisture content of the soil.

Sampling for Anatomical Studies

Three plants per genotype were randomly selected 100 days after sowing for anatomical examination. Stem segments (3 to 4 cm) consisting of both bark (phloem) and wood (xylem) were taken from the upper, middle and lower parts of the stem. These materials were preserved in a Formalin-Aceto-Alcohol (FAA) solution (10 ml of Formalin, 5 ml of 85% glacial acetic acid and 85 ml of 70% alcohol) (Verma, 2008).

Preparation of Transverse Sections and Data Collection

Transverse sections (0.3 to 0.5 mm) were cut with a hand microtome, washed with distilled water and stained with 1% aqueous safranin. The stained sections were fixed in glycerin-water and viewed under a compound microscope according to standard histological principles (Tolivia and Tolivia, 1987; Gärtner and Schweingruber, 2013).

The following anatomical parameters were recorded: bark diameter, bark thickness, number of trapezoids per section, fibre bundle layers per trapezoid, bundle cell number, trapezoid width, trapezoid area, distance from trapezoid to epidermis and trapezoid height. Laboratory work took place during the first week of October 2023.

Hybridization and Diallel Crossing

All seven parental genotypes were grown in earthen pots in a crossing block. The seeds were planted in two lots at 20-day intervals to synchronize the blossoming. A full diallel mating design, including all direct and reciprocal crosses, was followed (Griffing, 1956) (Table 1).

Table 1. Full diallel cross combinations among seven white jute genotypes, including direct and reciprocal crosses.

Parent	C-870	C-2262	C-5002	C-5036	C-5149	CC-45	BJRI deshi pat 9
C-870		×	×	×	×	×	×
C-2262	×		×	×	×	×	×
C-5002	×	×		×	×	×	×
C-5036	×	×	×		×	×	×
C-5149	×	×	×	×		×	×
CC-45	×	×	×	×	×		×
BJRI deshi pat 9	×	×	×	×	×	×	

In the afternoon, an emasculation was carried out by removing the anthers from the flower buds, which were expected to open the following morning, and then the flowers were bagged. Pollination took place the following morning (07:00 to 09:00) using fresh pollen from the male parental species. Pollinated flowers were marked, and the bags were removed after successful fertilization. The mature capsules were harvested, and the F_1 seeds were cleaned, dried in the sun with 7 to 8 percent moisture, and stored in desiccators with silica gel for future use.

Results and Discussion

Anatomical Traits Associated with Fiber Yield Potential

In jute, the yield and quality of bast fiber are mainly driven by the development of the secondary phloem, which determines anatomical characteristics as a reliable indicator of fiber potential. The study showed significant genotypic differences across all the anatomical parameters assessed, highlighting significant genetic diversity and scope for improvement (Figure 1).

Bark diameter and thickness, which serve as indicators of fiber-bearing tissue extent, varied significantly among the genotypes. C-2262 and C-870 had the largest diameter of the bark, while C-870 had the largest thickness of the bark (Figures 2 and 3); these findings are consistent with previous studies (Sengupta and Palit, 2004; Zhang et al., 2019) and indicate an increase in secondary phloem expansion and increased deposition of fibers. These findings are in line with the findings of Mukul et al. (2020), which reported that the basal part of the tossa jute plant has the largest stem diameter and fiber content, which is a significant factor in the fiber yield potential and serves as a major criterion for the development of the variety.

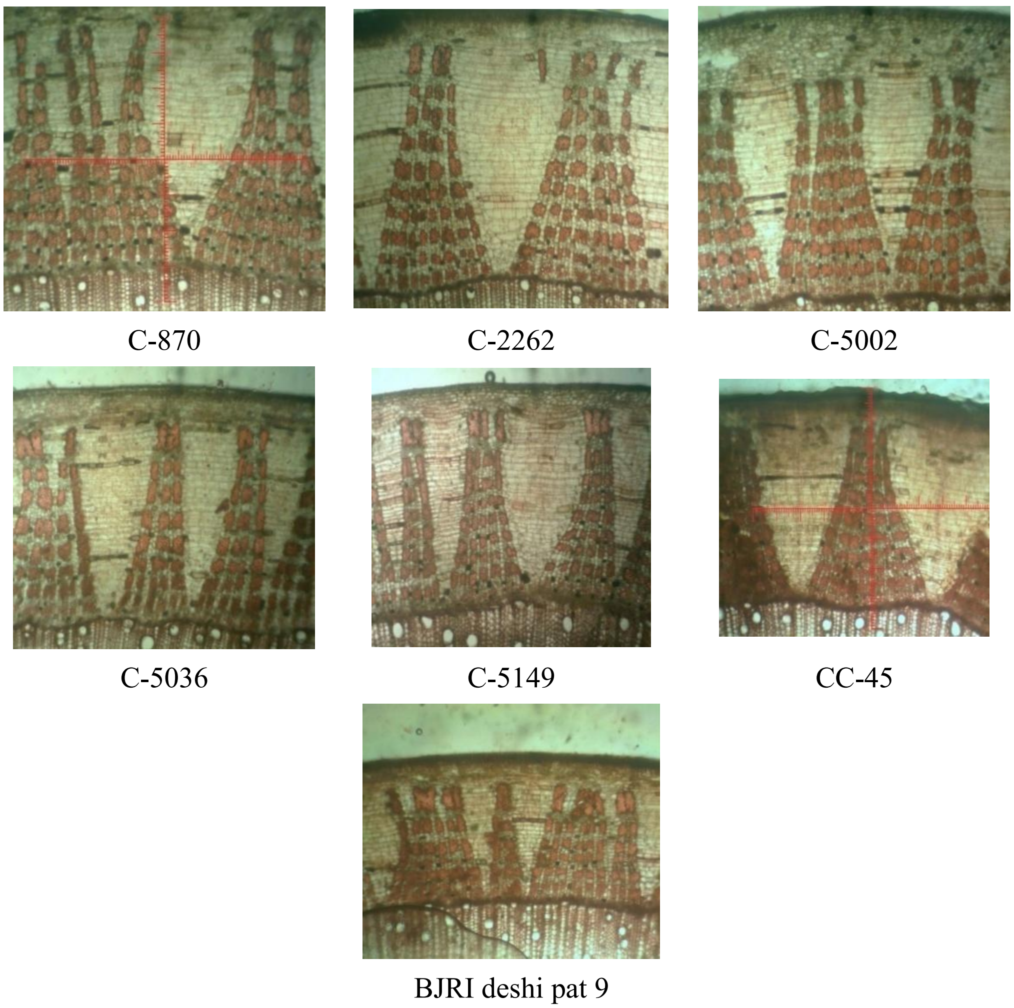

Fig. 1. Transverse stem sections showing fibre bundle compactness in selected white jute genotypes.

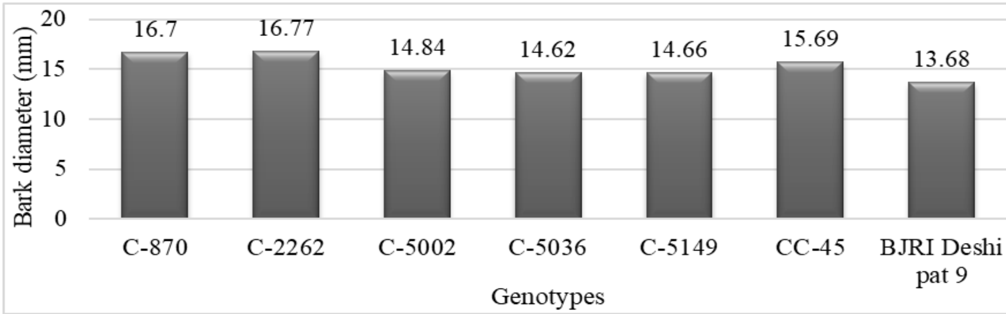

Fig. 2. Bark diameter of selected white jute genotypes measured at 100 days after sowing.

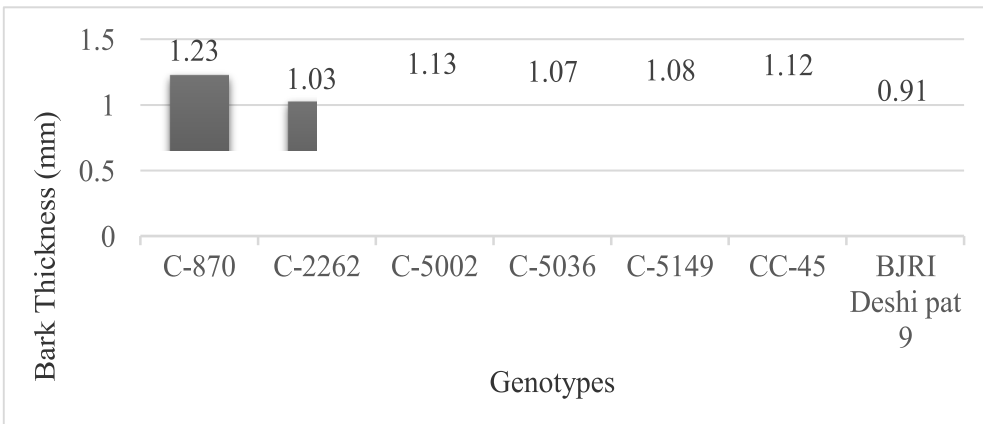

Fig. 3. Bark thickness of selected white jute genotypes measured at 100 days after sowing.

The fiber bundles are arranged in trapezoidal configurations, with both the number of trapezoids and the number of bundle layers per trapezoid contributing to the total fiber yield. Although C-5002 produced the highest number of trapezoids (Figure 4), C-870 and C-2262 had a better fiber-bundle layering (Figure 5), which directly contributes to the compactness of the fiber and to the overall biomass of the fiber (Pervin and Haque, 2012).

Genotypes with higher plant height and basal diameter produced more trapezoids per transverse section, resulting in a larger total area of fibrous fiber. The increased number of trapezoids contributes directly to the increased fibrous covering tissue and ultimately to the increased fiber yield potential. Similar findings have been reported by Sengupta and Palit (2004) and Mukul et al. (2020). In addition, the area of fibre bundles and fibre yield in jute are strongly affected by the number of fibre bundles in each bundle (Pervin and Haque, 2012).

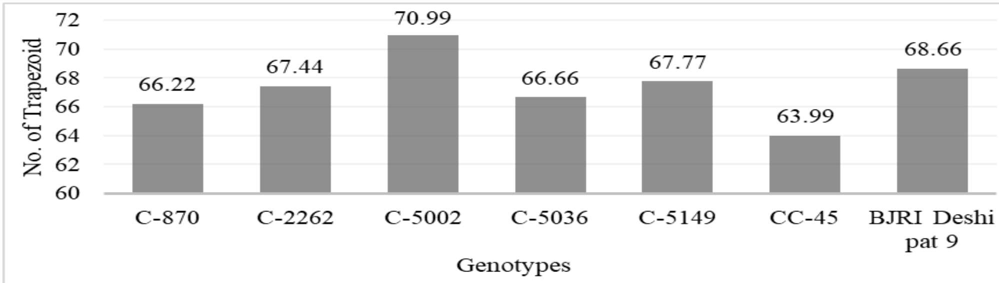

Fig. 4. Number of trapezoids per transverse stem section in selected white jute genotypes.

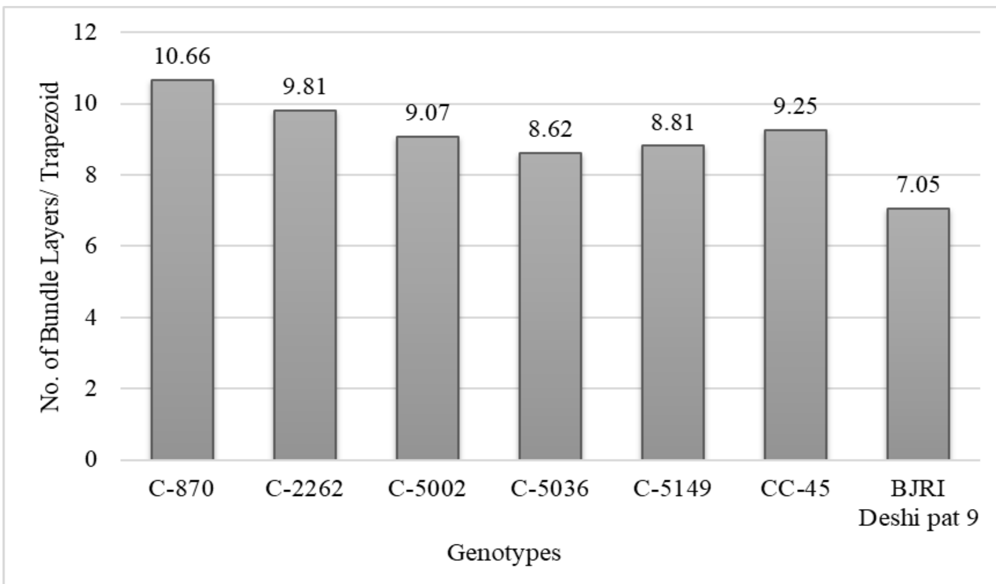

Fig. 5. Number of fiber bundle layers per trapezoid in selected white jute genotypes.

The number of bundle cells per trapezoid and the total trapezoid area are the main determinants of the thickness, strength and overall yield of the fiber. C-870 had the highest number of bundle cells, followed by C-2262 (Figure 6); both genotypes had significantly larger trapezoid regions compared with CC-45 and BJRI deshi pat 9 released (Figure 7). Increased trapezoidal areas indicate a higher deposition of fibers and serve as reliable indicators of fiber yield (Satya et al., 2011; Maiti and Satya, 2009).

Higher fiber yields are generally associated with jute genotypes with larger trapezoid regions, as the larger trapezoid region reflects a larger deposition of fibers in the secondary plasma. Therefore, larger trapezoid genotypes can be a promising parental line for hybridization programmes aiming at increasing fiber yield and quality (Mukul et al., 2020).

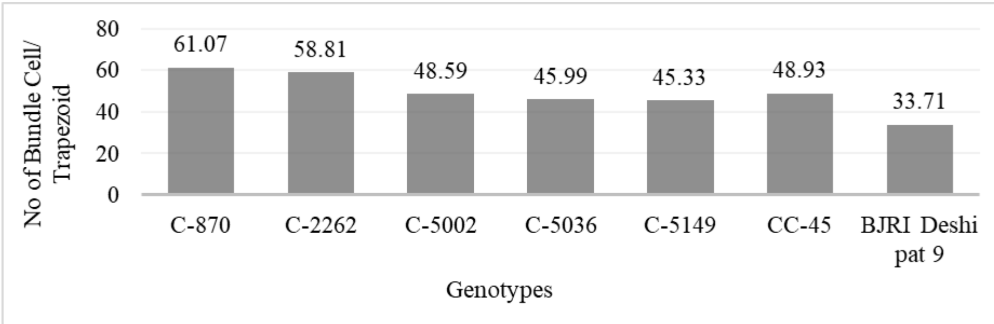

Fig. 6. Number of bundle cells per trapezoid in selected white jute genotypes.

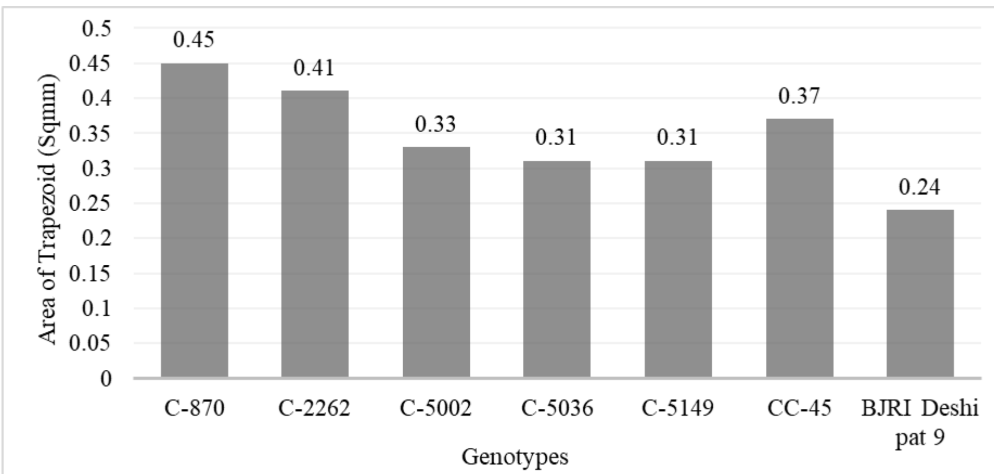

Fig. 7. Trapezoid area in selected white jute genotypes.

The distance between the trapezoid and the epidermis showed significant differences between the genotypes evaluated in white jute, suggesting differences in the organization of the stem tissue. C-5002 had the highest distance, while C-5149 had the lowest distance (Figure 8). The greater distance between the epidermis and the trapezoidal structures with the fibrous lining may be due to differences in cortical thickness and the organization of the internal tissues. Although this characteristic is not directly related to fiber yield, it may influence the efficiency of fiber extraction and the processing characteristics of the stem. In addition, the trapezoid height varied, with C-870 and C-5002 exceeding the released varieties (Figure 9), thus extending the productive area of fiber production.

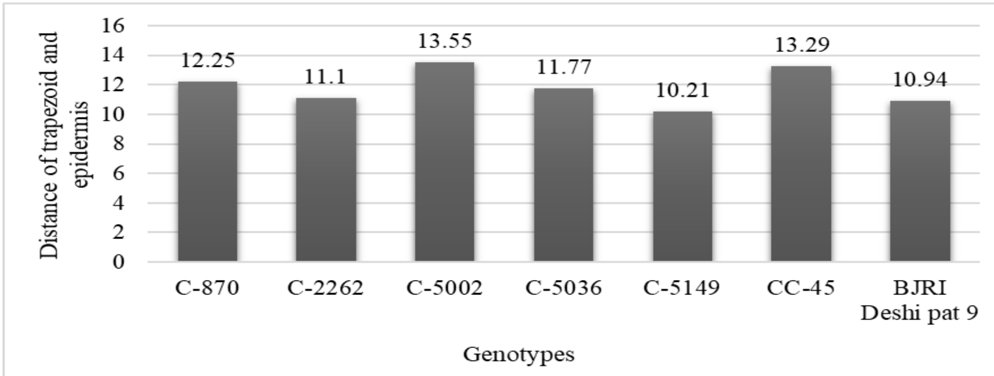

Fig. 8. Distance between trapezoid and epidermis in selected white jute genotypes.

The observed genotypic differences indicate an underlying genetic difference in the anatomical structure of the stem, which may be useful in selecting for better fibre processing qualities in the production programmes of white jute. Overall, C-870 and C-2262 performed well on the various fibre-related metrics, including bark development, fiber bundle organization, bundle cell count, and trapezoid area. These findings highlight the usefulness of anatomical screening as a non-destructive method of early selection in breeding programmes for white jute.

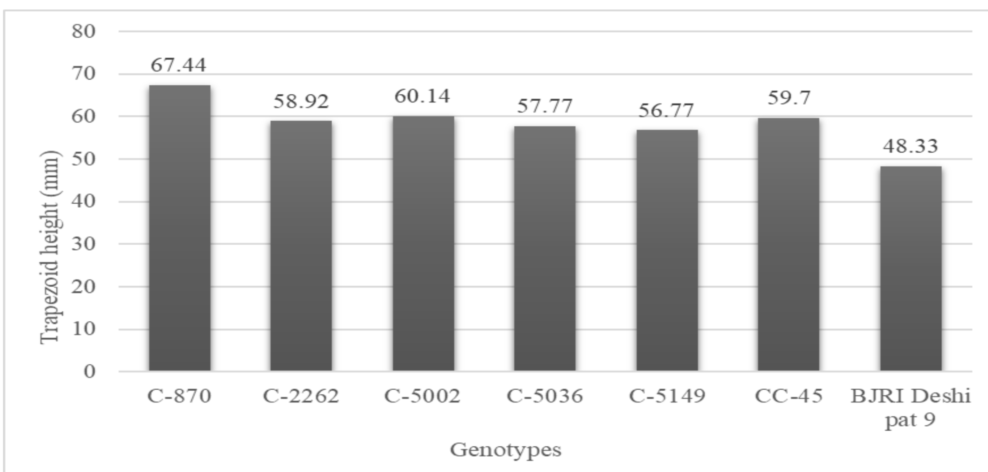

Fig. 9. Trapezoid height in selected white jute genotypes.

Hybridization Success and Breeding Implications

Hybridization helps to create variability by pooling desirable genes for qualitative and quantitative characteristics from different parental species. This allows the desired characteristics to be combined by hybridization and the selection of better offspring for the purposes of varietal improvement (Buerkle et al., 2013; Zhou et al., 2012). Breeders must look for variability to develop new varieties (Caligari and Foster, 2015). A complete diallel mating system including seven genotypes resulted in 48 successful crossings out of 95 attempts, i.e., 50.52 percent cross compliance (Table 2). This moderate degree of compatibility between the parental lines reflects an acceptable compatibility. Two populations of breeding stock with desirable characteristics are inbred until homozygosity, usually at 90 percent or more (Al-Mamun et al., 2022). Crosses containing C-870 and C-2262 had a higher success rate, indicating good flower synchronization and genetic affinity.

Table 2. Number of attempted and successful crosses among white jute genotypes under a full diallel mating design.

Sl. No.	Male		Female	No. of crosses	No. of successful crosses
1	C – 870	×	C – 2262	1	1
2		×	C – 5002	4	3
3		×	C – 5036	7	5
4		×	C – 5149	3	1
5		×	CC – 45	1	1
6		×	BJRI deshi pat 9	2	0
7	C – 2262	×	C – 870	2	2
8		×	C – 5002	1	1
9		×	C – 5036	3	1
10		×	C – 5149	3	1
11		×	CC – 45	7	3
12		×	BJRI deshi pat 9	2	1
13	C – 5002	×	C – 870	5	2
14		×	C – 2262	1	1
15		×	C – 5036	3	1
16		×	C – 5149	3	1
17		×	CC – 45	7	3
18		×	BJRI deshi pat 9	2	1
19	C – 5036	×	C – 870	1	0
20		×	C – 2262	1	1

Sl. No.	Male		Female	No. of crosses	No. of successful crosses
21		×	C – 5002	2	0
22		×	C – 5149	1	0
23		×	CC – 45	1	1
24		×	BJRI deshi pat 9	2	0
25	C – 5149	×	C – 870	4	3
26		×	C – 2262	2	1
27		×	C – 5002	2	1
28		×	C – 5036	2	1
29		×	CC – 45	2	1
30		×	BJRI deshi pat 9	2	0
31	CC – 45	×	C – 870	1	0
32		×	C – 2262	2	1
33		×	C – 5002	1	1
34		×	C – 5036	1	0
35		×	C – 5149	1	0
36		×	BJRI deshi pat 9	3	1
37	BJRI deshi Pat 9	×	C – 870	2	1
38		×	C – 5002	2	1
39		×	C – 2262	2	2
40		×	C – 5036	5	1
41		×	C – 5149	2	1
42		×	CC – 45	2	1
			Total	103	48

By combining anatomical data with hybridization results, C-870 and C-2262 were identified as elite parental lines for increased fiber yield. The crossing of these two genotypes shows particular promise for the development of separate populations with higher fiber yields and quality. This combined approach minimizes the need for destructive fiber assessment and makes it easier to implement a more effective and sustainable strategy for improving white jute.

Conclusion

The study revealed significant genotypic differences in fibre-related anatomical characteristics between white jute lines, which confirmed that anatomical characterization is a reliable and non-destructive method for predicting fiber yield potential. Advanced breeding lines C-870 and C-2262 consistently outperformed standard varieties in the development of the bark, the layering of the fiber bundle, the number of bundle cells, and the trapezoid area, which indicate a higher fiber production capacity. The diallel programme further confirmed their breeding value, achieving a 50.52 percent overall cross-compliance and demonstrating moderate compatibility with reproduction. In particular, the hybrid combination C-870 × C-2262 has a strong potential to develop a higher segregation population with improved fiber yield and quality. Overall, the integration of anatomical screening and hybridization provides an effective, efficient and sustainable strategy to improve fiber yield and quality in white jute and to support the rapid development of improved cultivars for future breeding programmes.

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