Fiber Anatomy Structure: a Good Predictor for Fiber Yield and Fiber Quality in *Corchorus capsularis*

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Abstract

Prediction of fiber yield and quality are essential in jute breeding program. Plant height and basal diameter are moderately reliable indicators of fiber yield in jute, but these characters are not useful to judge fiber quality owing to the large variability of fiber contents and fiber bundle structure which is again dependent on retting condition. Fiber anatomical characters are useful indicators for judging fiber yield and quality, but are rarely used in breeding programs. A rapid method for screening white jute (*Corchorus capsularis*) is described and the usefulness of fiber anatomy characters for predicting fiber yield was studied in comparison to morphological characters. Results indicate that fiber anatomical characters are highly suitable for predicting fiber yield and quality.

1. Introduction

Jute is the most important natural bast fiber crop of the world being grown primarily in south-east Asian countries and some parts of South America. Prediction of yield by studying component characters is very crucial in jute breeding. Bast fibers are part of vegetative biomass as they are formed in the secondary phloem regions in jute stem. Since whole plant is to be harvested and retted for direct estimation of fiber yield, the plant does not reach to the reproductive stage and no seed can be harvested from such plant. In a breeding population, jute breeder thus rely more on indirect estimation of fiber yield by using component characters such as plant height and stem diameter. The heritability and correlation of these two characters have been found to be variable depending on environmental conditions, retting methods and management practices (Chaudhury, 1988). Moreover, none of these characters can predict fiber quality and thus are unsuitable for fiber quality improvement.

Anatomical studies have long been used for determination of fiber quality in jute (Kundu et al., 1959; Maiti, 1973, 1977; Maiti et al., 2011). Few attempts have been made to link anatomical characters with fiber yield, but these results were genotype specific and have not been validated on a larger number of genotypes (Maiti and Satya, 2010). We here report a quick and reliable method for screening anatomical characters with their suitability for predicting fiber yield and quality characters. To establish the utility, the method was validated in a set of twenty *Corchorus capsularis* (white jute) genotypes and compared with morphological characters for predicting fiber yield and quality.

2. Materials and Methods

2.1. Experiment and plant character study

A set of twenty selected germplasm accessions of *C. capsularis* from National Active Germplasm Site of jute and allied fibers, Central Research Institute for Jute and Allied Fibers, Kolkata, India were selected for the present study along with two released varieties JRC 212 and JRC 321. The genotypes were grown in April-July, 2010 in randomized complete block design with two replications. Standard management practices were followed for raising a good crop, and crop was harvested at the age of 120 days. Observations were recorded on eleven plant morphological characters including plant height, stem diameter (basal, middle and top), node number, number of branches, internode length, green biomass, green biomass without leaf, green fiber weight and dry fiber weight. Fore dry fiber weight, jute plants were retted in experimental retting tanks for 18 days.

2.2. Fiber anatomy

A rapid and non-destructive method for fiber anatomy study was used for the present study. At harvest age, random healthy plants were selected and a bark region of 1 cm^2 was carefully removed from the stem at 0.50 m height from the base of the stem with sharp razor blade. The cut sections were immediately preserved in formalin: acetic acid: alcohol (5: 15: 80) solution, labeled properly and stored for further anatomical studies. Hand-free cross-sections were prepared using sharp blade and the sections after rinsing with water (5 m) to remove additional mucilage were stained with 1% safranin (aqueous) solution. Stained sections were blotted dry and mounted with a drop of glycerin on a clear glass slide with a cover slip. Observations were recorded on eleven qualitative and quantitative fiber anatomical characters.

2.3. Statistical analysis

The correlations of plant and fiber quality characters were calculated using Statistical Package for Social Science (SPSS). Regression of both plant and fiber characters on fiber yield were performed using Fast Statistics and validated using SPSS.

3. Results and Discussion

The purpose of the study was to compare contribution of plant morphological and fiber anatomical characters towards fiber yield and to provide a reliable estimate of fiber quality from anatomical characters. Thus the exact values of plant and fiber characters are not presented, although significant variability was observed for all the characters studied. This signifies the suitability of the present population for further analysis. The plant and fiber characters of some high performing accessions are presented in Table 1.

Genotype CIJ 153 exhibited better performance than check varieties for plant characters, fiber yield, biomass, plant height, basal diameter and green fiber weight. Anatomical observations on fiber cross-section revealed that CIJ 153 also has higher length of fiber wedge, higher number of fiber bundles wedge^{-1}, better regularity of fiber and low lignification (Plate 1).

Similarly, CIJ 143 exhibited better performance for fiber yield, biomass, basal diameter, green fiber weight, and number of fiber edges cross-sectional area^{-1}. But for other fiber characters it was not better than the check varieties. Higher fiber yield in this genotype is thus contributed by more number of

Table 1: Genotypes with superior performance for plant and fiber characters

No.	Character	Superior accessions	Performance of check variety
1	Fiber yield (g plant^{-1})	CIJ 153 (16.26), CIJ 143 (14.32), CIJ 122 (14.24)	JRC 212 (9.56), JRC 321 (12.14)
2	Biomass (g plant^{-1})	CIJ 122 (372.6), CIJ 143 (363.8), CIJ 153 (336.2)	JRC 212 (290.6), JRC 321 (301.8)
3	Plant height (cm)	CIJ 153 (375.2), CIJ 092 (375.0), CIJ 125 (373.3), CIJ 122 (373.0)	JRC 212 (355.0), JRC 312 (344.0)
4	Basal diameter (mm)	CIJ 122 (21.22), CIJ 139 (20.17), CIJ 153 (20.05), CIJ 143 (20.02)	JRC 212 (20.01), JRC 321 (17.54)
5	Green fiber weight (g plant^{-1})	CIJ 122 (82.0), CIJ 153 (79.0), CIJ 143 (64.8)	JRC 212 (57.6), JRC 321 (54.2)
6	Number of fiber wedges cross-sectional area^{-1}	CIJ 143 (84.76), CIJ 139 (84.36), CIJ 094 (78.81)	JRC 212 (66.2), JRC 321 (88.6)
7	Length of fiber wedges (µm)	CIJ 135 (87.3), CIJ 153 (85.7), CIJ 026 (84.1)	JRC 212 (72.2), JRC 321 (46.4)
8	Number of fiber bundles wedge^{-1}	CIJ 153 (72.0), CIJ 122 (62.4), CIJ 026 (60.5)	JRC 212 (62.0), JRC 321 (42.0)
9	Regular shape and surface of fiber bundle	CIJ 006, CIJ 026, CIJ 122, CIJ 153 (all regular)	JRC 212 (regular), JRC 321 (irregular)
10	Meshiness	CIJ 092 (minimum), CIJ 094 (minimum)	JRC 212 (low), JRC 321 (low)
11	Lignification	CIJ 006, CIJ 026, CIJ 063, CIJ 086, CIJ 092, CIJ 094, CIJ 122, CIJ 126, CIJ 139, CIJ 153 (low)	JRC 212 (low), JRC 321 (medium)

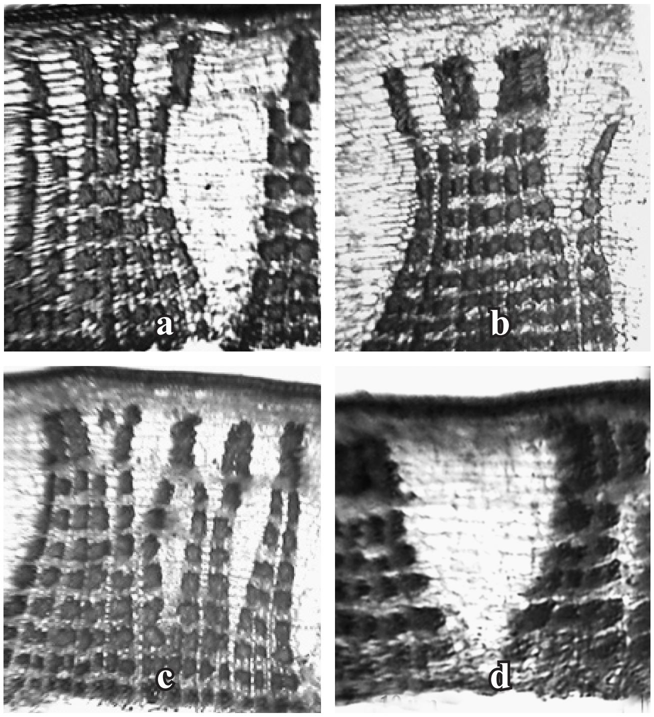

Plate 1: Fiber anatomy of white jute (a. CIJ 153, b. CIJ 122, c. JRC 212 and d. JRC 321)

fiber wedges, which compensates for length of fiber wedges and number of fiber bundles wedge^{-1}. CIJ 122, on the other hand exhibited higher fiber yield, biomass, plant height, basal diameter, green fiber weight and more number of fiber bundles wedge^{-1}. It also has regular fiber bundle shape, less meshiness and low lignin, indicating the fiber quality of this genotype is better than the check varieties. Two genotypes, CIJ 092 and CIJ 094, although inferior to check varieties for yield, exhibited minimum meshiness of fiber, a highly desirable criterion in industry for combing of fiber.

The correlations of fiber yield (g plant^{-1}) with different morphological and fiber anatomy characters are presented in Table 2.

In general, morphological characters exhibited higher correlation with fiber yield than fiber anatomy characters. Plant height, basal diameter, middle diameter, biomass with and without leaf, and green fiber weight showed significant positive correlation with fiber yield. On the other hand, number of fiber wedges stem^{-1} cross-sectional area, length of fiber wedge, number of fiber bundles wedge^{-1}, total breadth of green fiber and individual fiber bundle length exhibited significant positive correlation with fiber yield indicating that these traits contribute significantly to fiber. As expected, the pericarp and protophloem regions, which do not contribute to

Table 2: Correlation of morphological characters with fiber yield in *C. capsularis*

Morphological characters	Correlation with fiber yield	Fiber anatomy characters	Correlation with fiber yield
Plant height (cm)	0.62*	Number of fiber wedges stem^{-1} cross-sectional area	0.38*
Basal diameter (mm)	0.75**	Number of transverse layers wedge^{-1}	0.32
Middle diameter (mm)	0.66**	Inner width of fiber wedge (μm)	0.19
Top diameter (mm)	-0.26	Length of fiber wedge (μm)	0.62**
Number of nodes plant^{-1}	0.75**	Number of fiber bundles wedge^{-1}	0.47*
Number of branches plant^{-1}	-0.04	Pericarp thickness (μm)	0.27
Internode length (cm)	0.23	Protophloem thickness (μm)	0.15
Biomass at harvest (g plant^{-1})	0.84**	Total breadth of green fiber (μm)	0.61**
Biomass without leaf (g plant^{-1})	0.81**	Individual fiber bundle length (μm)	0.42*
Green fiber weight (g plant^{-1})	0.75**	Individual fiber bundle width (μm)	0.27
		Number of fiber cells fiber^{1} bundle	0.32

*Significant at 5% level, **Significant at 1% level

the harvestable fiber, did not show significant correlation with fiber yield. The results are partly in accordance with Chen et al. (1990), who found positive correlation between number of fiber bundles and fiber yield in *C. capsularis*. However, they have observed high correlation between number of fiber cells bundle^{-1} and fiber yield. In the present study, more number of parameters was selected and it was found that length of fiber wedge, which corresponds to the fiber cross-sectional radius exhibits highest correlation with fiber yield.

Regression analysis using fiber yield as dependant variable and ten plant characters using independent variables revealed a good fit (R^2=0.81, Adjusted R^2=0.63). The following relationship was observed:

Fiber yield (g plant^{-1})=(-4.50) + 0.01 x plant height (cm) + 0.49 x basal diameter (mm) + 0.54 x middle diameter (mm) + 1.20 x top diameter (mm) + 0.18 x number of nodes plant^{-1} + 0.21 x number of branches plant^{-1} + 0.12 x internode length (cm) + 0.01 x biomass (g) + 0.03 x biomass without leaf (g) + 0.06 x green fiber weight (g plant^{-1})

It can be observed from the regression equation that basal diameter, middle diameter and top diameter have shown better contribution towards fiber yield compared to other characters. On the other hand, plant height and green biomass, although having good correlation with fiber yield are contributing less towards fiber yield and thus are less reliable for using as selection criteria. This is supported by Prakash et al. (2004) who observed lower genetic advance of plant height and higher genetic advance for basal diameter in *C. capsularis*. Thus using plant height as a reliable predictor for fiber yield might be misleading. The harvest index of jute germplasm (fiber weight/green biomass) varies from 4 to 6.5%, in comparison to grain crops (40-50%). So, green biomass may not be a good predictive criterion for fiber yield in white jute.

When regression analysis was performed on fiber yield using fiber anatomy characters, the equation was found to be a better fit (R^2=0.85, Adjusted R^2=0.69). The relationship was expressed as:

Fiber yield (g plant^{-1})=(-21.41) + 0.25 x number of fiber wedges plant^{-1} + 0.37 x number of transverse layers fiber^{-1} wedge + 0.1 x inner width of fiber wedge (μm) + 0.11 x number of fiber bundle wedge^{-1} + 0.05 x thickness of pericarp (μm) + 0.002 x thickness of protophloem (μm) + 0.035 x thickness of the bark (μm) + 0.18 x individual fiber bundle length (μm) + 0.13 x individual fiber bundle width (μm) + 0.26 x number of fiber cells fiber^{-1} bundle

The relationship clearly identifies that number of fiber wedges plant^{-1}, number of transverse layers fiber^{-1} wedge, individual fiber bundle length, individual fiber bundle width and number of fiber cells fiber^{-1} bundle contribute primarily to the fiber yield. Moreover, the estimation is independent of retting process, as these major component characters are directly related to the fiber, but not to other cellular components that are removed by retting process. It is expected that selection of more diverse genotypes having wide differences in yield and fiber characters will improve the regression equation and the contributions of the component characters will be clearer. Our present study contradicts the findings of Chen et al. (1990) that plant height is more reliable character for indirect selection, and supports the observations of Maiti (1977) that fiber anatomy characters are better indicator of fiber yield. Moreover, as discussed, estimation of fiber quality and fineness is only possible through fiber anatomy study, thus providing better advantage for selection of improved genotypes with better quality. Mazumdar (2002a, b) using regression equation showed that fiber bundle structures have been found to be related with strength and fineness, the two major quality parameters of jute.

Fiber quality of the accessions were predicted from the fiber anatomical characters described earlier as well as from five additional qualitative characters, namely shape of fiber bundle, surface of fiber bundle, extent of interconnection of fiber layers, lignification of fiber bundle and cavity area of single cell. Four types of shapes were observed in the fiber bundle: rectangular, square, ovoidal polygon and irregular wavy. Surface of the fiber bundles were noticed to be highly irregular, irregular or regular. While square and rectangular shapes are indicative of smooth and finer fibers, wavy and irregular fibers and polygonal shapes predict inferior quality fibers as the fiber bundle surfaces along the length will be rough and uneven, decreasing the quality of fiber for textile purpose. Earlier studies have reported that *C. capsularis* has higher meshiness and fiber surface irregularity than *C. olitorius* (Maiti and Satya, 2010). In the present study, according to the extent of interconnection, genotypes were characterized to be either having minimum, low, medium or high interconnection. High interconnection indicates higher meshiness of fiber, thereby increasing the chance of breakage of fiber cells during combing process. However, meshiness is a desirable character while preparing gunny bags, fiber composite boards or for geotextile purpose, as the higher interconnections helps better integration of foreign particles, thus increasing the strength and durability of the final structures. The genotypes CIJ 153 exhibited better quality fiber than both the checks JRC 212 and JRC 321 (Figure 1). It can be observed that CIJ 153 (Figure 1a) exhibits better fiber wedge length, higher number of fiber bundles and less meshiness. On the other hand, JRC 212 produces finer and more regular fiber than JRC 321, as evident from the fiber bundle structure (Figure 1c and 1d). Lignification was estimated from the extent of staining of fiber cells. Accordingly, the genotypes were categorized into less (11), medium (9) and highly lignified (2) fibers. High lignification indicates fiber strength, while low lignification is a characteristic feature of finer fiber. Similarly, the genotypes were also classified according to single fiber cell cavity into two groups: low cavity area (6) and high cavity area (16). Hao et al. (1993) suggested that small cellular cavity of fiber cells is an important character for fiber quality improvement. Thus the identified genotypes having low lignin, meshiness and low cavity may be useful for jute finer fiber quality breeding.

4. Conclusion

In conclusion, we have demonstrated that fiber anatomy characters are good predictors of fiber yield than morphological characters. Moreover, with the help of rapid screening technique described above, breeding materials could be easily screened for both fiber yield and quality without the need of direct estimation of fiber yield and quality. Anatomical study in jute therefore has great potential to predict the yield and quality of fiber.

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