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A Non-destructive Selection Criterion for Fibre Content in Jute

III. The Criterion and its Prospects

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Summary. A new prediction formula using a geometrical description of the jute plant is proposed and was found to predict the single plant fibre yield to a remarkable degree of accuracy. After an incisive evaluation of 20 component characters, plant height, basal and mid-diameters, basal and mid-sample fibre densities were selected to formulate the non-destructive prediction criterion. Its superiority was upheld when tested in five environments extending over a period of three years, 110 genetically distinct entries and 3080 single plants. The prospects of this criterion in reorienting the existing breeding technology and devising new ones are discussed.

Key words: Selection – Fibre – Jute – Estimation – Breeding

Introduction

Breeders of bast fibre crops and expecially of jute (*Corchorus olitorius* L. – 'Tossa' jute, and *C. capsularis* L. – 'White' jute) are faced with the problem of the non-availability of a sound criterion for selection for fibre yield. Since the small-pod stage, optimum for retting the jute plant for fibre, occurs long before seed maturity, it is all the more necessary to evolve a non-destructive method of estimating fibre yield so that a plant can be left for seed collection if found to have a high fibre yield potential. A precise method of fibre estimation would help to reorient the current breeding approaches for this crop. New breeding concepts would then rely only on a single character, fibre yield, instead of several biometrical variables. It would also become possible to bypass some routine breeding steps.

Studies initiated earlier (Iyer et al. 1974; Arunachalam and Iyer 1974) in order to evolve a precise method of fibre estimation were continued with the following major objectives in view:

a) Identification of characters that can be measured before the small-pod stage which would be adequate to estimate single plant fibre yield

b) to formulate, using those characters, the process of estimation

c) to check the formula's efficiency and to determine its domain of application

d) to underline possible new approaches of breeding for fibre yield.

Materials and Methods

The material included a spectrum of widely divergent genotypes from the species *capsularis* and *olitorius*. In addition to a number of released varieties under cultivation, segregating progenies of physical and chemical mutants, inter-specific hybrids in different generations, mutants isolated for leaf, stem or pod characters and trisomic derivatives were included (Table 1). They were grown at Delhi and Pusa, Bihar from 1972 to 1974 during the rainy seasons in the following environments: E1 – Delhi, 1972; E2 – Pusa, 1972; E3 – Delhi, 1973; E4 – Delhi, 1974 and E5 – Pusa, 1974. For operational ease, fibre yield was obtained from bundles of 10 plants in E1 and E2. While the material was raised in four replications in E1 and E2 and three in E3, with a single block per replication, they were grown unreplicated in each of nine blocks in E4 and E5.

In E1 to E3, observations were recorded on random samples of ten plants on a large number of characters in an attempt to search for an optimum combination with which to estimate the fibre yield. The height of the jute plant was divided into four equal parts at the points K, H, L (Fig. 1). In E1 and E2, the point K was chosen to be at a height of 15 cm above ground level.

Bark samples measuring 5 cm × 1 cm were removed (Fig. 1) from regions with centres at L, H and K, and denoted respectively by Top (T), Middle (M) and Base (B). Care was taken not to have them along the same vertical nutrient path. Such samples were collected in E3 from two more regions selected at random between the heights, LH and HK, denoted P and Q, respectively. The barks were retted chemically, the diameters at these positions noted and the fibre yield of the samples were obtained as detailed in Arunachalam and Iyer (1974). The following is the list of characters observed:

E1 and E2: 1. Flowering time, 2. Plant height, 3 to 5. Diameters, 6 to 8. Bark thickness, 9 to 11. Bark weight, 12 to 14. Dry fibre weight of samples at the positions T, M and B, 15. Fibre yield of 10 plant bundles.
E3: 1. Flowering time, 2. Plant height, 3. Number of internodes, 4 to 8. Diameters, 9 to 13. Dry fibre weight of samples, 14 to 18. Inter-nodal lengths, at the positions, T, P, M, Q, B, 19. Fibre-wood ratio, 20. Single plant fibre yield.

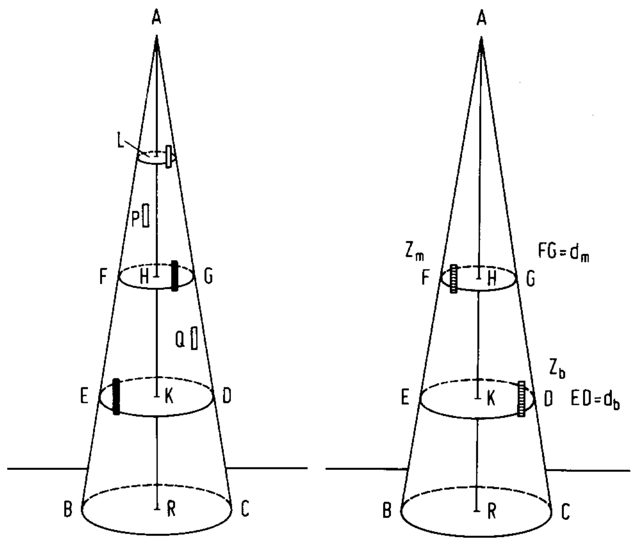

Fig. 1. Geometric representation of jute plant

The jute plant frame was approximated by a cone (Iyer et al. 1974) and the fibre yield was obtained as a product of the surface area and fibre density. The total surface area was calculated as the sum of the respective areas of a cone from the tip of the plant axis to the point R (see Fig. 1) and one or more frustums from the rest of the plant configuration. A number of combinations of such cones and frustums was tried in order to estimate total fibre yield. The actual number of bark samples and the regions from where they should be taken were decided on the basis of the configuration which gave the closest estimate to the actual fibre yield in the environments E1 to E3. The ability of the characters to estimate fibre yield was evaluated by a multiple regression approach in E1 and E2 (Arunachalam and Iyer 1974) and was confirmed by the same method in E3 (Table 3). Combining the information obtained on the geometric and regression approaches over the environments, E1 and E3, it was decided to measure the following characters only in E4 and E5: (1.) Plant height (cm), (2.) Mid-diameter (at the position M, in mm), (3.) Mid-fibre (= dry fibre weight of the sample taken in the region M, in mgm), (4.) basal diameter (at the position B, in mm), (5.) Basal fibre (= dry fibre weight of the sample taken in the region B, in mgm). In all the environments, plants were individually retted and fibre yield obtained to compare them with the estimated yield (except in E1 and E2 where fibre yields of bundles of 10 plants were obtained). The final geometric formula for estimating fibre yield is explained in the Appendix. Using the fibre yield thus obtained as a dependent variable, a multiple regression equation to predict fibre yield was set up. Thus, two formulae became available for estimation of fibre yield; one geometric, to be denoted by G hereafter, and the other through multiple regression, to be denoted by R. The goodness of agreement between the actual and estimated fibre yields was tested by chi-square after standardising them. For convenience, we shall denote by n, the number of single plants or 10-plant bundles used for fibre estimation. The term, agreement percent, denoted by p hereafter, implies the percentage of plants where the differences between actual and estimated fibre yields were in many cases near zero, and in no case significant at 5% level, as tested by chi-square.

Results

Representation of a jute plant by a regular geometric figure was found to be adequate for an effective estimation of fibre yield. Further, five samples of bark taken along the length of the plant could provide as high as 96% agreement (Table 2). But the method of estimating fibre yield

Table 1. Material used in different environments

Material	*E1		*E2		E3		E4		E5	
	e	n	e	n	e	n	e	n	e	n
'OLI'-V	2	8	2	8	5	150	18	625	18	623
OLI-M	3	12	3	12	5	150	12	173	–	–
'CAP'-V	2	8	2	8	1	30	7	262	7	240
CAP-M	3	12	3	12	2	60	20	344	–	–
ISH	–	–	–	–	–	–	6	94	–	–
TRS	–	–	–	–	–	–	2	157	–	–
LSP-M	–	–	–	–	–	–	19	78	–	–
Others	–	–	–	–	–	–	3	14	–	–
Total	10	40	10	40	13	390	87	1747	25	863

e = number of genetic entries; n = number of plants;
* = bundles of 10 plants; OLI = *olitorius*; CAP = *capsularis*;
V = variety; M = mutant; ISH = Inter-specific hybrids;
TRS = trisomics; LSP = leaf, stem or pod

Table 2. Efficiency of fibre samples taken at different positions of jute plant

Samples at	l.c.		
	E1	E2	E3
5 positions	not available		96
T,M,B	70	65	96
T,B	73	80	96
M,B	70	65	96

Table 3. Potency of some characters to predict fibre yield

Characters	f	
	*E1 and E2	E3
Plant height	15	14
Basal diameter	8	8
Mid-diameter	9	8
Basal fibre	7	8
Mid-fibre	11	8
Top diameter	4	6
Top fibre	4	5
Basal bark weight	3	–
Mid-bark weight	5	–
Number of nodes	–	2
Basal internode length	–	1
Mid-internode length	–	1
Fibre-wood ratio	–	2

f = frequency of occurence in 18 regression equations under E1 and E2 and 14 under E3, which showed a coefficient of determination of 70% and above.
* from Arunachlam and Iyer (1974)

should entail minimum labour and maximum efficiency if it is to be utilised effectively in screening large populations. Based on such a criterion, a minimum of two bark samples was found necessary. The sample at B is indispensable if the estimate is to be the least affected by tapering of jute plants. Hence, the two combinations of bark samples, T, B and M, B, were tested and found to be equally good. However, the former had a slight edge over the latter in E1 and E2 (Table 2). Since the fibre yield data were affected by the relatively higher loss of fibre during retting of 10-plant bundles in E1 and E2, the above result should be viewed with reservations. Moreover, removing a bark sample of 5 sq.cm from the region T is definitely arduous (and sometimes impossible in plants tapering sharply). Hence the combination M,B is the better of the two.

This decision was upheld by the multiple regression analysis. When a set of regression equations, involving various combinations of component characters and having a coefficient of determination of at least 70%, were examined (Table 3), top diameter and top fibre ranked definitely lower than mid-diameter and mid-fibre. Further, the five characters – plant height, basal- and mid-diameter and basal- and mid-fibre – had a consistently high potential to estimate fibre yield in E1 to E3 (Table 3), regardless of the range of genetic material (and also of 10-plant fibre in E1 and E2 in contrast to single plant fibre in E3).

Table 4. Goodness of agreement between observed and estimated fibre yields

Environment	l.c.		
	n	G	R
E1	40	93	90
E2	40	100	93
E3	390	97	96
E4	1747	97	97
E5	863	97	96

Table 5. Analysis of entries where agreement was absent

Environment	n	f		
		G	R	C
E1	40	3	4	2
E2	40	0	3	0
E3	390	12	16	10
E4	1747	57	58	25
E5	863	23	37	11

f = number of plants where agreement was absent
C = number of plants common to both G and R

The geometric and regression formulae constructed (see Appendix) were tested by comparing the agreement percent in a wide range from over 100 genetically divergent entries, five distinctly different environments and more than 3000 single plants (Tables 1 and 4). While the geometric formula gave a remarkable agreement, the regression formula was equally efficient (Table 4). An analysis of the entries where the agreement was below the norm (as tested by chi-square) revealed that most of them were common to both G and R (Table 5). Since the frequency of such entries was small, it was feasible that human error in retting and measuring other characters played a role in bringing about such a result. Under adequate precautions to ensure accuracy of data, agreement was obtained to a remarkable degree in E4 and E5 (Tables 4 and 5).

In order to detect whether the efficiency of the proposed formula was variety-specific, diverse genetic material, including segregating entries, induced mutants, trisomic derivatives and interspecific hybrids in various generations, were included in E4 and a portion of them in E5.

Table 6. Variety-wise analysis of goodness of agreement

Entry	Environment	n	l.c.	
			G	R
'OLI'-V	E4	625	97	96
	E5	623	98	96
'CAP'-V	E4	262	97	96
	E5	240	98	97
OLI-M	E4	173	99	100
CAP-M	E4	344	97	95
ISH	E4	94	97	97
TRS	E4	157	96	94
LSP-M	E4	78	95	96
Others	E4	14	100	100
Overall		2610	97	95

Table 7. Mean and standard errors of observed and estimated fibre yield

Environment	Mean			Standard Errors		
	O	G	R	O	G	R
E1	15.9	17.6	17.6	5.04	4.93	3.76
E2	15.3	17.9	17.9	4.78	4.82	3.81
E3	22.7	26.0	26.0	7.83	8.70	8.59
E4	6.9	6.7	6.7	3.10	3.27	3.19
E5	7.8	8.7	8.7	3.93	4.31	4.21

O – observed

Table 8. Efficiency of prediction of fibre yield under different sample sizes

Environment	Plant Samples	n	P	
			G	R
E4	1 – 101	100	94	92
	1 – 312	300	93	93
	1 – 747	600	96	96
	1 – 1043	900	96	96
E5	1 – 104	100	97	99
	1 – 310	300	97	97
	1 – 622	600	98	97

The results showed more than 95% agreement both with G and R, with a slight edge in favour of G (Table 6). The efficiency of estimation would be apparent on comparing the experimental mean single plant fibre yield, its estimates by G and R and their standard errors (Table 7).

It was then pertinent to ask the question whether the regression formula was prone to sample size, possible with any statistical equation. The results based on seven samples of various sizes indicated that the efficiency of R was not directly related to sample size (Table 8). However, R was found to be sensitive even to a few discrepancies in the data.

Discussion

The studies reported here clearly demonstrate that it is possible to efficiently predict the fibre yield of jute sufficiently before its harvest for fibre or seed. In fact, all the characters utilised in the new formula can be measured as soon as the elongation of plant height ceases to be appreciable, by which time the major biological processes concerning fibre development will also have been completed.

The geometric formula of fibre yield has been unique in being able to predict fibre yield to a remarkable degree of accuracy regardless of the environments and the nature of the material. In turn, it implies that the characters used are the most stable and important ones for determining fibre yield. When the fibre density was calculated from 5 samples, two of which were taken at random in the regions between T,M and M,B, there was no marked improvement in the precision of the estimates. This shows that the distribution of fibre from the base to the tip of the plant is regular and in accordance with the degree of tapering. For that reason, it was not possible to cut the number of samples to the absolute minimum. Thus we may say that the character variables used in the formula belong to the class of optimum and minimal sets. Whether one can discover more such sets is an open but interesting question.

The criteria of selection followed by jute breeders centres mostly around character correlations observed in small experiments using varying genetic material. In general, the nature of association is not consistent over time or space. In a comprehensive review of breeding approaches in jute, Basak et al. (1974), stated that the deficiencies associated with traditional approaches like character correlations, heritability, discriminant function and selection index, were their absence of consistency and repeatability. They pointed out in particular, that any criterion of breeding or selection based on plant height and basal diameter alone is bound to fail. Our studies have also shown that characters like flowering time, number of internodes and fibre-wood ratio have no direct bearing on fibre estimation. Roy and Mandal (1967) reported, in this connection, the possibility of both seed collection and fibre extraction from the same plant, despite the delay in the retting process resulting in coarse and low-quality fibre. The formulae that we have proposed in this paper, makes this possibility applicable but without affecting seed collection, fibre extraction and fibre quality.

As a next step, we now evaluate the prospects of estimating fibre yield by G against its alternative R. The geometric formula has a singular advantage in being independent of the size of the population, of unexpected discrepancies in measurements, from environmental influences and from the genetic nature of the material. On the other hand, discrepant measurements may affect the dispersion matrix of variables and thereby the linear regression formula. In contrast, such discrepancies entering G will affect the fibre estimates of only those plants where they were present. The only argument in favour of R is that it takes into account character associations peculiar to environments in space and time. If the situation is carefully analysed, it can be argued that such associations will readily influence the measurements and hence become automatically incorporated in G. We observe, therefore, that the geometric formula of fibre yield is adequate for estimation and prediction, and can be supplemented by regression formula whenever estimation of fibre is to be done on large areas.

We conclude by highlighting the following prospects of the non-destructive estimation and prediction formula, G in jute breeding:

1. A wooden frame mounted with iron pieces with sharp edges enclosing a rectangular area of 5cm × 1cm has served us as an efficient and inexpensive instrument to peel off the two bark samples. This has been found to save a lot of time, especially when the number of single plants to be handled is large.

2. When a large area is covered by a pure line variety, it is possible to sample the area, utilise the formula G and predict the total fibre yield. This technique applied on a national scale will help to forecast the amount of fibre that will be available to jute industry much in advance so as to allow the industry to come to crucial management decisions in time.

3. Breeding for fibre yield will be very much simplified through the proposed method of fibre estimation for the following major reasons:

a) The formula is almost immune to environmental effects and genetic variability of the material. Thus fibre yield of segregating genotypes at any stage of the breeding programme can be found.

b) The non-destructive method employed will be very helpful for collecting the seeds, especially those of heterozygotes. They can then be used for pedigree breeding or in further hybridisation.

c) The need to employ component characters, directly and indirectly associated with yield, in selection programmes can be dispensed with in preference to direct selection for estimated fibre yield.

d) Biometrical analyses, especially to gather information on combining ability, can be confined to the five component characters and fibre yield. Multiple crosses, with heterozygous parental bases, can be planned with ease since a decision to use a growing plant as a parent can be taken much before it comes to flowering (based on the estimate of fibre yield).

e) Breeding and selection for pure lines, most appropriate to this highly self-pollinated crop, can be done with ease starting from a genetically broad multiple cross base using fibre yield alone.

4. The process of fibre estimation (both by G and R) using a computer programmed initially on field data, has been found to work quite fast in facilitating large scale applications of this criterion.

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Appendix
Estimation of Fibre Yield in Jute

A. *Geometric Formula*

d_m = Mid-diameter = FG (mm); d_b = Basal diameter = ED (mm)
AR = h (cm); AH = h/2; HK = KR = h/4
z_m = Mid-fibre (mgm); z_b = Basal fibre (mgm)
$r_m = 0.5\ d_m$; $r_b = 0.5\ d_b$
Total fibre yield = * Fibre yield of (Cone AFG + Frustum BCGF) $= \Pi\ (Y + W)$ say
Density of fibre in the cone AFG, $f_m = 0.2\ z_m$ (mgm/sq.cm)
Density of fibre in the frustum BCGF, $f_b = 0.1\ (z_m + z_b)$ (mgm/sq.cm)

$$Y = 0.2\ z_m \times 0.5\ d_m \sqrt{d_m^2 + h^2)/4}$$
$$= 0.05\ d_m z_m \sqrt{d_m^2 + h^2}$$

From the regular frustum, BCGF, it is easy to see that,
ED = 0.5 (FG + BC)
i.e., $d_b = 0.5\ (d_m + BC)$

$BC = 2\,d_b - d_m$
i.e., $0.5\,BC = r_c = d_b - 0.5\,d_m$

$$W = 0.1\,(r_m + r_c)(z_m + z_b)\sqrt{(r_c - r_m)^2 + 0.25h^2}$$
$$= 0.1\,d_b\,(z_m + z_b)\sqrt{(d_b - d_m)^2 + 0.25\,h^2}$$

Total fibre yield in gm

$$= 0.0001\,\Pi\,[0.05\,z_m\,d_m\sqrt{d_m^2 + h^2} + 0.1\,d_b\,(z_m + z_b)\sqrt{(d_b - d_m)^2 + 0.25\,h^2}]$$
$$= 0.00001\,\Pi\,[2z_m d_m\sqrt{d_m^2 + h^2} + d_b\,(z_m + z_b)\sqrt{(d_b - d_m)^2 + 0.25\,h^2}]$$

* For formulae of areas of regular surfaces, see 'Handbook of Chemistry and Physics', 46th edition. (ed. Weast, R.C., et al., pp. A-202, A-203, Ohio, U.S.A.: The Chemical Rubber Co., 1965-1966.

B. *Regression Formula*

The estimates of fibre yield (gm) obtained by geometric formula were used as dependent variable (Y) and a linear multiple regression equation using X_1 (plant height), X_2 (mid-diameter), X_3 (mid-fibre), X_4 (basal diameter) and X_5 (basal fibre) was fitted by the usual statistical procedure.

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5$$

Environment	b_0	b_1	b_2	b_3	b_4	b_5
E1	−24.0	0.46	0.17	0.98	−2.90	0.44
E2	−23.8	0.60	5.79	0.14	−1.75	−1.29
E3	−50.9	0.07	0.07	0.16	1.48	0.08
E4	−14.2	0.04	0.20	0.06	0.45	0.03
E5	−17.6	0.04	0.50	0.06	0.58	0.03

The s.s. due to regression and all the regression coefficients were highly significant at 1% level in each environment.

The observed and estimated fibre yields (by G and by R) were standardised using their respective means and standard errors (Table 7) and the goodness of agreement of observed with expected values was tested by single d.f. chi-square, for each single plant. There was good overall agreement between observed and expected values when pooled over all the single plants in each environment.

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