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Elucidation of Genetics of Fibre Yield and Quality Traits in Tossa Jute (*Corchorus olitorius* L.) Using Generation Mean Analysis

Vinod Ashok Kale[1], Suvendu Kumar Roy[2], Avijit Kundu[3], S. Vishnupriya[2], Moumita Chakraborty[2], Lakshmi Hijam[2], Bilin Maying[2], Saikat Das[4], Sanghamitra Rout[5], Bandan Thapa[6] and Dinesh Tulsiram Surje[7]

[1]Eagle Seeds & Biotech Limited, Indore, Madhya Pradesh (452 010), India
[2]Dept. of Genetics and Plant Breeding, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal (736 165), India
[3]AICRN on Potential Crops, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal (736 165), India
[4]AICW&BIP, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal (736 165), India
[5]Dept. of Genetics and Plant Breeding, CUTM, Paralakhemundi, Odisha (761 211), India
[6]Regional Research Station, Hill Zone, Uttar Banga Krishi Viswavidyalaya, Kalimpong, West Bengal (734 316), India
[7]Kewalramji Harde College of Agriculture, Chamorshi, Maharashtra (442 603), India

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Corresponding suvendukumarroy@gmail.com

0000-0001-9343-5756

ABSTRACT

The present study was conducted at Uttar Banga Krishi Vishwavidhyalaiya, Cooch Behar, West Bengal, India during Pre-*kharif* season (premonsoon from April–July) of 2011, 2012 and 2013. It was observed that the six generations, P_1, P_2, F_1, F_2, BC_1 and BC_2 of all the three crosses, differed significantly for all the traits studied, except fibre percentage in case of all the crosses and basal diameter in case of cross C_3 (OIN 580×JRO 128). Scaling tests as per Mather (1949) revealed the presence of epistatic interactions for almost all the traits except basal diameter in OIN 580×JRO 128. Duplicate epistasis was observed for majority of the traits and there was total absence of complementary epistasis. The joint scaling test confirmed the inadequacy of the additive-dominance model in most of the crosses for majority of the traits, indicating the influence of duplicate epistasis in their expression. It also revealed a significant additive ×additive (i) and dominance×dominance (l) types of epistasis in all three crosses for fibre yield plant^{-1}, fibre tenacity and fibre fineness. It was thus recommended to opt for pedigree method of conventional breeding with delayed selection to later generations for simultaneous improvement of tossa jute (*Corchorus olitorius* L.) fibre yield and quality.

KEYWORDS: Tossa jute, epistasis, gene action, generation mean analysis

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1. INTRODUCTION

White jute (*Corchorus capsularis*) is an important bast fibre-producing crop (Mukul et al., 2022). It is a widely cultivated fibre species with important physiological properties such as biomass, a deep root system, and tolerance to metal stress (Saleem et al., 2020). Jute plants grow in grassy soils and require 125–150 mm of rainfall month^{-1}, mild to moderate temperatures (20–40°C), and high relative humidity (70–80%) for optimal growth (Ullah et al., 2017). Jute is also called the golden fibre for its color and high cash value (Islam., 2019). From the point of view of sustainability and mechanical properties, jute fiber is better than many natural or synthetic fibers (Sayem and Haider, 2019). Also, the use of jute fibers as reinforcement for the development of composites has increased in modern times as environmental exasperation from rising fuel prices, fossil fuel depletion, and global warming (Singh et al., 2018). Like any other natural fiber, jute fiber performance varies due to natural variability in surface and internal microstructural properties (Chandekar et al., 2020). Knowledge of the genetic composition of a trait helps plant breeders to plan their breeding programs to get a stable performing genotype (Fahad et al., 2018). The breeding value of the genotype is decided by the results of genetic analysis (Selvakumar et al., 2022).

The available genetic models have been further expanded to estimate the different genetic effects (Adebayo et al., 2014). Most of such models like line×tester, diallel and North Carolina design (NSD) are additive-dominance models, where epistatic or non-allelic interactions are not considered which results in over estimation of gene actions or underestimation of the non-allelic gene interactions (Pujar et al., 2022). It is well known that additive and dominant effects and their interactions are called as gene actions which are reported to be associated with breeding value (Falconer and Mackay, 2013). These inter-allelic interactions occur in high frequency and have an influence over the control of continuous expression of genes (Moharramnejad et al., 2016). The magnitude and type of interallelic interactions or epistasis can influence the reliability of predictions and breeding strategies. Therefore, genetic analysis using generation mean analysis will help in designing the most appropriate breeding approaches for developing high yielding varieties (Ramli et al., 2016).

The generation mean analysis has been extensively used to study the gene effects of quantitative traits for several crops like chickpea (Deshmukh and Gawande, 2016), cotton (Yadav et al., 2020), barley (Madakemohekar et al., 2018), rice (Ganapati et al., 2020), mustard (Prajapati et al., 2014), pearl millet (Pujar et al., 2022), sesame (Daba et al., 2015), bread wheat (Lal et al., 2013), maize (Moharramnejad et al., 2018), soybean (Uzokwe et al., 2017), cowpea (Owusu et al., 2022), tomato (Al-Gumar and Ahmad, 2020), etc. But rarely it has been used in case of jute (*Corchorus sp.*) as evidenced by lack of earlier reports on the same as the production of the crop for fibre, is restricted to a very few eastern states only within India and in a very few countries across the globe. The main advantage of this generation mean analysis is that it informs us about the average effects of the genes (additive effects), dominance effects and effects due to epistatic interactions which can assist in quantifying the genotypic value of individuals. Scaling and joint scaling tests are established mechanisms used by conventional breeders to understand allelic and non-allelic gene actions, nature and magnitude of genetic variance of genotypes in specific combinations. Hence, the present investigation has been undertaken out to study the gene effects in three crosses of tossa jute (*Corchorus olitorius* L.) for various components of fibre yield and quality traits.

2. MATERIALS AND METHODS

The experiment was carried out at Instructional Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India during the pre-*kharif* season (premonsoon from April–July) of 2011, 2012 and 2013. The farm is situated at 26° 19' 86" N latitude and 89° 23' 53" E longitude with an altitude of 43 m above the mean sea level. In 2011 two high fibre yielding tossa jute (*C. olitorius*) genotypes namely JRO 128 and JRO 620, two having good fibre tenacity namely JRO 878 and OIN 580 and two finer fibre quality genotypes, OIJ 015 and OIN 574 were selected for three crosses viz., C_1 (OIJ 015×JRO 878), C_2 (OIN 574×JRO 620) and C_3 (OIN 580×JRO 128), for carrying out the generation mean analysis, following the six- parameter-model as suggested by Jinks and Jones (1958).

During 2012, these three crosses were selfed and backcrossed with their respective parents to obtain the F_2 and backcross (BC_1 and BC_2) generations, respectively. Selfed seed was also obtained for all the parents. To obtain the F_1 seed to be used in 2013 once again all the three crosses were repeated in 2012. Thus, 6 basic generations, P_1, P_2, F_1, F_2, BC_1 and BC_2 were developed for each of the three crosses. In 2013, evaluation of P_1, P_2, F_1, F_2, BC_1 and BC_2 generations was undertaken in Randomized Block Design with 3 replications in rectangular plots of size 1.5×2 m^2 area, in which there were five rows of 2 m length. The row to row and plant to plant spacing was 30 cm and 10 cm, respectively. The recommended packages of practices were followed to raise a good crop. The observations were recorded on six yield atributing traits namely plant height (cm), basal diameter (mm), green weight plant^{-1} (g), stick weight plant^{-1} (g), fibre percentage (%), fibre yield plant^{-1} (g) and two quality traits namely fibre tenacity and fibre fineness. The number of plants per replication from which data was recorded varied in the individual generations. In each P_1, P_2 and F_1 five plants were used, in each back crosses BC_1 and BC_2 ten plants and in F_2 twenty plants were used. The data was recorded from the respective number of selected plants in each of P_1, P_2, F_1, F_2, BC_1 and BC_2, in each replication for the traits plant height, basal diameter, green weight, stick weight, fibre percentage and fibre yield on per plant basis and the two quality traits viz., fibre tenacity (g tex^{-1}) and fibre fineness (tex) on the basis of fibre samples from the selected plants. The two quality traits fibre tenacity and fibre fineness were recorded by the instruments Fibre Bundle Strength Tester (Model: NINFET-FBST-01) and Airflow Fineness Tester (Model: NINFET-AFT-01) respectively, from National Institute of Natural Fibre Engineering and Technology under Indian Council of Agricultural Research (ICAR-NINFET) [earlier ICAR-NIRJAFT], Tallygunj, West Bengal, India.

The data obtained was subjected to analysis of variance (ANOVA) using the Randomized Block Design as suggested by Panse and Sukhatme (1985). For all the eight traits under present study, the means of all the six generations (P_1, P_2, F_1, F_2, BC_1 and BC_2) of each of the three crosses were subjected to Scaling tests (A, B, C and D) as suggested by Mather (1949). This was also confirmed by the joint scaling test (Cavalli, 1952). If any of the scales A, B, C and D was found significant then the genetic effects were estimated by using the six-parameter model of generation mean analysis as suggested by Hayman (1958) to estimate the genetic parameters namely mean (m), additive gene effect (d), dominance gene effects (h) and the three types of non-allelic gene interactions namely additive×additive (i), additive×dominance (j) and dominance×dominance (l). The statistical analysis was done using the software 'Windowstat' (version 9.1) and GENRES (version-3.11 of 1994).

3. RESULTS AND DISCUSSION

The analysis of variance (Table 1) revealed that all the three crosses C_1 (OIJ 015×JRO 878), C_2 (OIN 574×JRO 620) and C_3 (OIN 580×JRO 128) differed significantly (p≤0.05 and p≤0.01) for all the traits studied except fibre percentage in case of all the crosses and basal diameter in case of C_3. The high level of variability for all the traits in the three Crosses under present study is also shown in the heat map (Figure 1). This indicated that further scaling test to detect the presence or absence of epistasis and the estimation of the genetic components might be carried out. This was supported by the the means of fibre yield and yield components and two quality traits (Table 2), which showed that the parent P_2 (JRO 878) outperformed the parent P_1 (OIJ 015) in the cross C_1 for fibre yield and most of the yield components except quality traits. In the cross C_2, P_2 (JRO 620) outperformed P_1 (OIN 574) for fibre yield and most of the yield components and one quality trait whereas P_1 (OIN 574) performed better than P_2 (JRO 620) for fibre percentage and fibre fineness. In C_3, P_2 (JRO 128) showed better performance for fibre yield and most of the yield related traits and quality traits except fibre fineness. The parents JRO 878, JRO 620 and JRO 128 performed better for fibre yield and most of the yield components along with quality traits except fibre fineness, thereby justifying its selection as high yielding parents in the three crosses studied.

Table 1: Analysis of variance of the six generations in the three crosses for fibre yield components and quality traits for parents and crosses in tossa jute (*C. olitorius* L.)

Sources of variation	Treatment df	Error df	Mean Sum of Squares		
			C_1 (OIJ 015×JRO 878)	C_2 (OIN 574×JRO 620)	C_3 (OIN 580×JRO 128)
Plant height (cm)	5	15	1263.61**	706.00*	667.00*
Basal diameter (mm)	5	15	3.17*	2.91*	0.65
Green weight $plant^{-1}$ (g)	5	15	2287.49**	3369.89**	3584.96**
Stick weight $plant^{-1}$ (g)	5	15	158.11*	293.86*	203.34*
Fibre percentage	5	15	0.68	3.07	1.47
Fibre yield $plant^{-1}$ (g)	5	15	14.95**	16.34**	14.99**
Fibre tenacity (g tex^{-1})	5	15	39.50**	51.92**	58.76**
Fibre Fineness (tex)	5	15	1.57**	1.10**	1.26**

** significant (p≤0.01); *significant (p≤0.05)

In a correlation study, the most important traits out of the total eight traits were fibre yield, fibre tenacity and fibre fineness for all the six generations of P_1, P_2, F_1, F_2, BC_1 and BC_2. A wide range of correlation (positive, negative and absence) between the three traits was observed in the three crosses under present study (Figure 2). It was revealed from

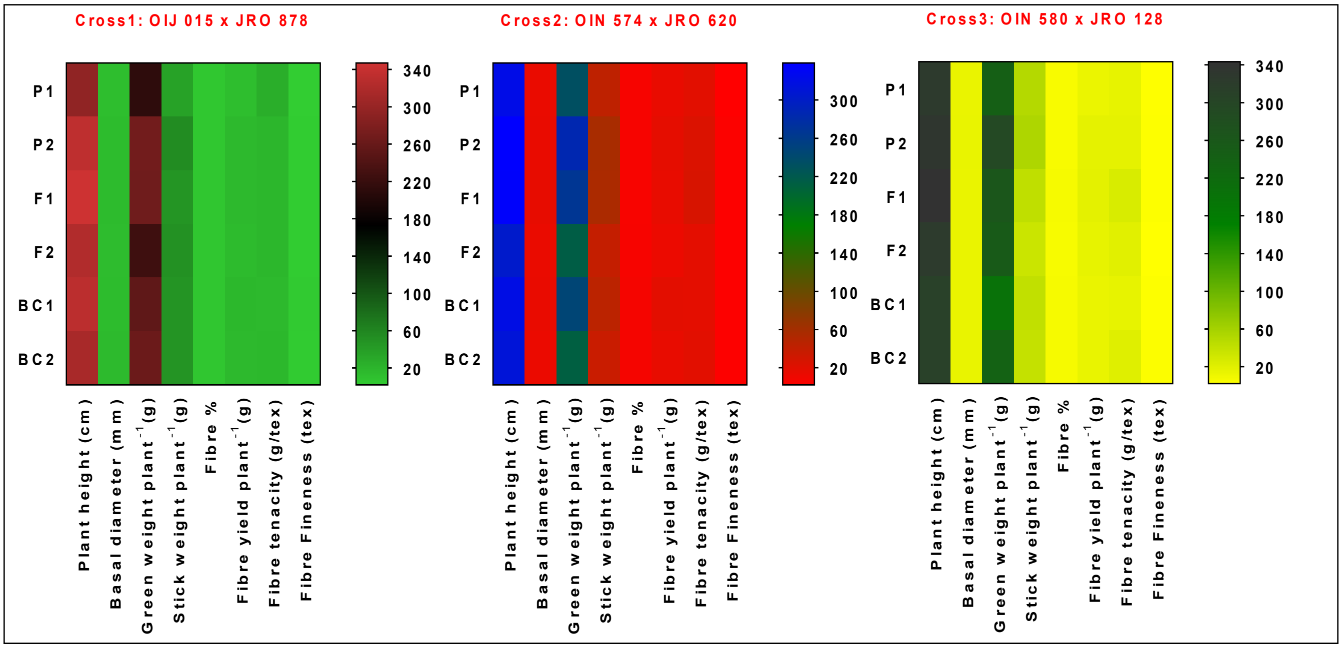

Figure 1: Heat map indicating the level of variability in the three crosses C_1, C_2 and C_3 for the eight traits under present study

Table 2: Mean performance of different generations of three crosses (C_1, C_2 and C_3) for fibre yield components and quality traits in tossa jute (*C. olitorius* L.)

Treatments	Plant height (cm)	Basal diameter (mm)	Green weight plant^{-1} (g)	Stick weight plant^{-1} (g)	Fibre percentage	Fibre yield plant^{1} (g)	Fibre tenacity (g tex^{-1})	Fibre fineness (tex)
C_1 (OIJ 015×JRO 878)								
P_1 (OIJ 015)	295.18	14.25	212.78	37.35	6.53	13.85	27.06	1.78
P_2 (JRO 878)	333.60	15.78	269.50	56.27	6.62	17.90	20.81	2.55
F_1	346.68	16.17	267.58	48.25	6.89	18.45	19.90	2.25
F_2	322.65	15.43	225.60	51.87	7.34	16.30	20.20	2.33
BC_1	331.47	15.61	253.85	49.60	7.58	19.25	18.29	3.65
BC_2	314.80	16.94	263.53	49.45	6.86	17.85	19.13	2.65
Mean	324.06	15.70	248.81	48.80	6.97	17.27	20.90	2.54
SEm (±)	13.45	0.52	20.72	5.09	0.37	1.33	0.24	0.10
CD (p=0.05)	28.66	1.11	44.15	10.85	0.79	2.83	0.51	0.21
C_2 (OIN 574×JRO 620)								
P_1 (OIN 574)	322.13	15.45	233.75	44.70	6.87	15.85	20.53	1.93
P_2 (JRO 620)	338.40	16.08	286.25	58.78	6.58	18.75	25.26	3.33
F_1	335.68	17.15	266.95	56.80	6.35	16.45	28.13	2.65
F_2	303.98	15.13	215.25	40.70	6.64	14.35	19.43	3.18
BC_1	320.23	16.24	246.93	46.70	8.19	19.95	19.48	3.20
BC_2	312.08	14.82	213.00	37.55	8.35	16.85	20.61	3.03
Mean	322.08	15.81	243.69	47.54	7.16	17.03	22.24	2.89
SEm±	12.70	0.72	27.95	4.72	0.73	1.58	0.31	0.10
CD (p=0.05)	27.06	1.53	59.56	10.06	1.56	3.37	0.66	0.21

Table 2: Continue...

Treatments	Plant height (cm)	Basal diameter (mm)	Green weight plant^{-1} (g)	Stick weight plant^{-1} (g)	Fibre percentage	Fibre yield plant^{-1} (g)	Fibre tenacity (g tex^{-1})	Fibre fineness (tex)
C_3 (OIN 580×JRO 128)								
P_1 (OIN 580)	325.10	15.53	243.00	52.15	6.36	15.10	17.53	2.40
P_2 (JRO 128)	332.65	16.53	292.25	56.00	6.60	19.20	18.81	3.05
F_1	343.20	15.97	264.40	44.15	7.61	19.80	27.43	2.95
F_2	323.25	15.55	253.83	36.85	7.29	18.00	21.62	2.00
BC_1	309.95	15.55	202.30	43.25	7.92	15.70	17.82	2.90
BC_2	310.18	16.09	237.45	41.25	7.45	16.30	23.18	3.63
Mean	324.06	15.87	248.87	45.61	7.21	17.35	21.07	2.82
SEm±	7.36	0.74	33.22	5.66	0.69	1.34	0.56	0.12
CD (p=0.05)	15.68	1.58	70.79	12.06	1.47	2.86	1.19	0.26

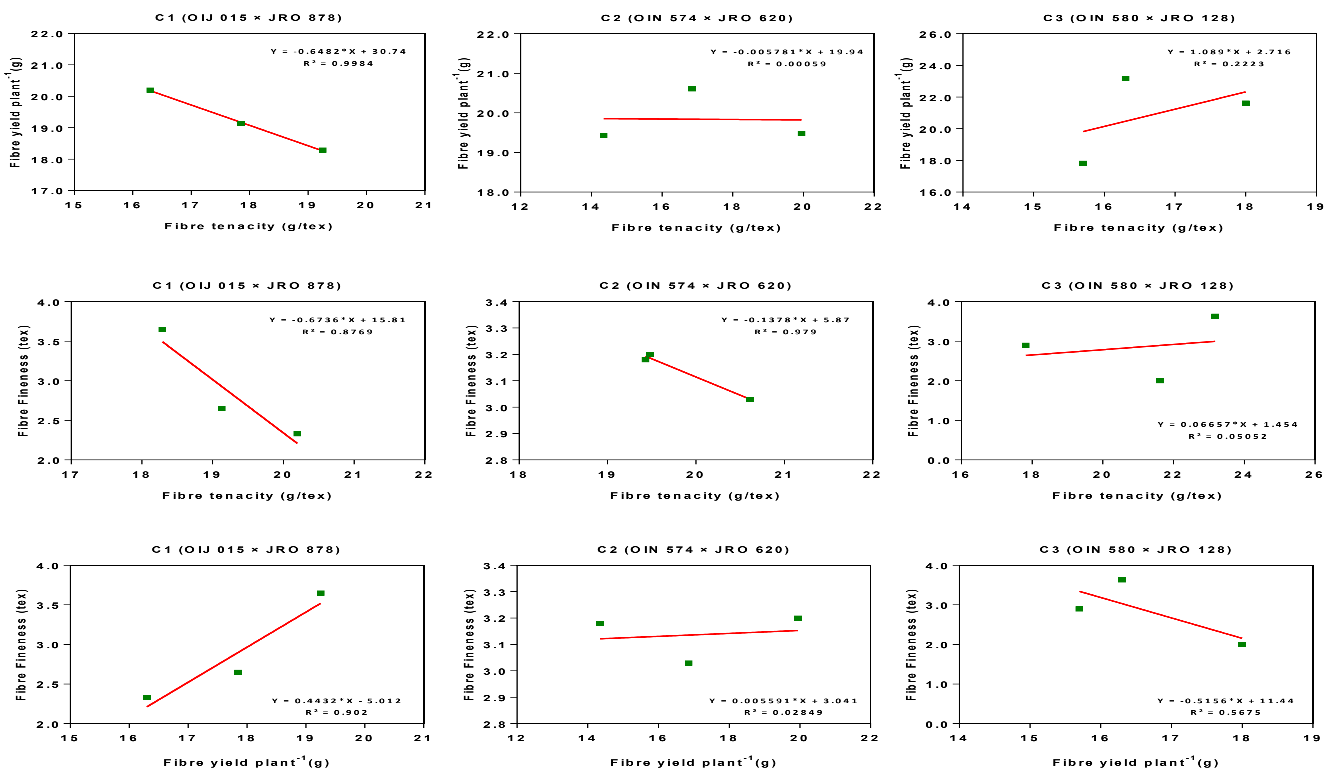

Figure 2: Correlation among fibre yield and the two fibre quality traits fibre tenacity and fibre fineness for the three crosses C_1, C_2 and C_3

the graphical presentation that positive correlation existed between fibre tenacity and fibre yield and between fibre tenacity and fibre fineness in the cross C_3 whereas, positive correlation was found between fibre yield and fibre fineness in the cross C_1. Negative correlation was found between fibre tenacity and fibre yield in C_1, between fibre tenacity and fibre fineness in C_1 and C_2 and between fibre yield and fibre fineness in C_3. Correlation was absent between fibre tenacity and fibre yield and fibre yield and fibre fineness in C_2.

The results of scaling tests as proposed by Mather (1949) presented in Table 3, revealed that simple additive - dominance model was inadequate for all the crosses for all the traits studied except for basal diameter in C_3. It indicated the importance of non-allelic interactions (epistasis) in most of the cases. Although estimation of non-allelic interactions (epistasis) was negligible by the earlier workers, however Khatun et al. (2010) reported existence of non-allelic interaction in F_2 for basal diameter, bark weight and stick

Table 3: Scaling test and gene effects of fibre yield components and quality traits in tossa jute crosses following six parameter model proposed by Jinks and Jones (1958)

Cross	Scale				Genetic component						Epistasis
	A	B	C	D	m	(d)	(h)	(i)	(j)	(l)	
Plant height (cm)											
C_1	21.10**	-50.68**	-31.53**	-0.98	312.44**	-19.21**	6.61	1.95	35.89	27.63	-
	(7.72)	(8.37)	(10.11)	(4.53)	(9.79)	(3.72)	(27.66)	(9.05)	(5.40)	(18.63)	
C_2	-17.35*	-49.93**	-115.98**	-24.35**	281.56**	-8.14**	35.54	48.70**	16.29	18.58	
	(6.63)	(9.54)	(12.48)	(6.47)	(13.17)	(2.42)	(34.16)	(12.95)	(5.23)	(22.36)	
C_3	-48.40**	-55.50**	-51.15**	26.38**	381.63**	-3.78**	-195.08**	-52.75**	3.55	156.65**	D
	(3.65)	(7.82)	(6.52)	(4.63)	(9.32)	(1.11)	(25.87)	(9.26)	(4.10)	(17.09)	
Basal diameter (mm)											
C_1	0.80	1.94**	-0.67	-1.70**	11.61**	-0.76**	10.71**	3.41**	-0.57	-6.14**	D
	(0.45)	(0.26)	(0.63)	(0.32)	(0.66)	(0.15)	(1.63)	(0.64)	(0.25)	(1.01)	
C_2	-0.12	-3.60**	-5.32**	-0.80	14.17**	-0.31*	0.86	1.60	1.74	2.12	
	(0.45)	(0.51)	(0.75)	(0.43)	(0.88)	(0.14)	(2.22)	(0.87)	(0.32)	(1.39)	
C_3	-0.41	-0.31	-1.79*	-0.54	14.96**	-0.50**	1.36	1.07	-0.05	-0.35	-
	(0.46)	(0.36)	(0.86)	(0.40)	(0.81)	(0.13)	(1.90)	(0.80)	(0.24)	(1.94)	
Green weight plant^{-1} (g)											
C_1	27.35*	-10.03	-115.03**	-66.18**	108.79**	-28.36**	308.46**	132.35**	18.69	-149.68**	D
	(13.18)	(11.56)	(17.99)	(7.54)	(16.41)	(6.47)	(43.40)	(15.08)	(8.43)	(28.15)	
C_2	-6.85	-127.20**	-192.90**	-29.43*	201.15**	-26.25**	-9.40	58.85*	60.18	75.20	-
	(16.53)	(19.45)	(25.46)	(12.60)	(25.72)	(5.14)	(69.48)	(25.20)	(11.19)	(47.19)	
C_3	-102.80**	-81.7**	48.75	67.90**	403.43**	-24.63**	-459.38**	-135.80**	-10.53	320.35**	D
	(15.82)	(26.93)	(36.83)	(21.18)	(42.56)	(4.09)	(106.13)	(42.36)	(14.50)	(66.72)	
Stick weight plant^{-1} (g)											
C_1	13.60**	-5.62**	17.35**	4.69	56.19**	-9.46**	-9.32	-9.37	9.61	1.39	-
	(3.44)	(1.68)	(6.10)	(2.93)	(5.95)	(1.05)	(13.61)	(5.85)	(1.72)	(8.16)	
C_2	-8.10**	-40.48**	-54.28**	-2.85	46.04**	-7.04**	-32.11*	5.70	16.19	42.88**	D
	(2.75)	(2.79)	(5.88)	(3.26)	(6.55)	(0.70)	(15.36)	(6.52)	(1.88)	(9.13)	
C_3	-9.80*	-17.65**	-49.05**	-10.80**	32.47**	-1.93	5.83	21.60**	3.93	5.85	-
	(4.18)	(2.55)	(5.22)	(2.46)	(5.07)	(1.26)	(13.32)	(4.91)	(2.19)	(8.86)	
Fibre percentage											
C_1	1.74**	0.20	2.42**	0.24	7.05**	-0.04	1.31	-0.48	0.77	-1.47	-
	(0.09)	(0.26)	(0.54)	(0.30)	(0.59)	(0.04)	(1.32)	(0.59)	(0.14)	(0.75)	
C_2	3.16**	3.78**	0.41	-3.27**	0.19	0.15*	19.63**	6.54**	-0.31	-13.48**	D
	(0.40)	(0.74)	(0.48)	(0.40)	(0.81)	(0.07)	(2.39)	(0.81)	(0.39)	(1.63)	
C_3	1.88**	0.70	0.97*	-0.80	4.88**	-0.12	6.91*	1.60	0.59	-4.17*	D
	(0.51)	(0.70)	(0.47)	(0.46)	(0.93)	(0.07)	(2.64)	(0.92)	(0.43)	(1.74)	
Fibre yield plant^{-1} (g)											
C_1	6.20**	-0.65	-3.45**	-4.50**	6.88**	-2.025**	26.13**	9.00**	3.43	-14.55**	D
	(0.89)	(0.61)	(1.13)	(0.36)	(0.83)	(0.43)	(2.27)	(0.71)	(0.51)	(1.54)	
C_2	7.60**	-1.50	-10.10**	-8.10**	1.10	-1.45**	37.65**	16.20**	4.55	-22.30**	D
	(0.88)	(0.97)	(1.71)	(0.80)	(1.62)	(0.30)	(3.97)	(1.60)	(0.56)	(2.56)	

Table 3: Continue...

Cross	Scale				Genetic component						Epistasis
	A	B	C	D	m	(d)	(h)	(i)	(j)	(l)	
C_3	-3.50** (0.81)	-6.40** (0.98)	-1.90 (1.72)	4.00** (0.95)	25.15** (1.89)	-2.05** (0.12)	-23.25** (4.58)	-8.00** (1.89)	1.45 (0.58)	17.90** (2.84)	D
Fibre tenacity (g tex^{-1})											
C_1	-10.39** (0.13)	-2.45** (0.17)	-6.88** (0.28)	2.98** (0.07)	29.89** (0.15)	3.13** (0.03)	-28.79** (0.40)	-5.96** (0.15)	-3.97 (0.06)	18.80** (0.34)	D
C_2	-9.70** (0.30)	-12.17** (0.22)	-24.33** (0.33)	-1.23** (0.21)	20.44** (0.42)	-2.37** (0.09)	-11.71** (1.13)	2.46** (0.41)	1.24 (0.18)	19.41** (0.72)	D
C_3	-9.32** (0.37)	0.12 (0.09)	-4.70** (0.42)	2.25** (0.09)	22.66** (0.25)	-0.64** (0.18)	-8.91** (0.65)	-4.49** (0.17)	-4.72 (0.18)	13.68** (0.43)	D
Fibre Fineness (tex)											
C_1	3.28** (0.09)	0.50** (0.05)	0.48** (0.07)	-1.65** (0.05)	-1.14** (0.10)	-0.39** (0.02)	10.46** (0.29)	3.30** (0.01)	1.39 (0.05)	-7.08** (0.19)	D
C_2	1.83** (0.04)	0.08 (0.07)	2.15** (0.10)	0.13** (0.05)	2.88** (0.09)	-0.70** (0.02)	1.43** (0.23)	-0.25** (0.09)	0.88 (0.04)	-1.65** (0.15)	D
C_3	0.45** (0.10)	1.25** (0.06)	-3.35** (0.13)	-2.53** (0.07)	-2.33** (0.14)	-0.33** (0.02)	12.03** (0.35)	5.05** (0.13)	-0.40 (0.05)	-6.75** (0.23)	D

**significant (p≤0.01) and *significant (p≤0.05); C_1: OIJ 015×JRO 878; C_2: OIN 574×JRO 620; C_3; OIN 580×JRO 128; D; Duplicate; Values in parenthesis indicate respective standard error (SE ±)

weight in white jute (*Corchorus capsularis* L.). The mean effect 'm' was significant in each case for different crosses except for fibre percentage and fibre yield plant^{-1} in C_2. The magnitude of the mean effect was found to be higher than the other genetic effects namely additive (d), dominance (h) and the three interaction effects namely additive×additive (i), additive×dominance (j) and dominance×dominance (l), among the three crosses for the traits plant height, basal diameter, stick weight and fibre tenacity.

Additive genetic effect (d) was predominant in most of the yield components and quality traits except stick weight plant^{-1} in C_3 and fibre percentage in C_1 and C_3. The magnitude of the additive genetic effect was higher than the dominance effect in C_1 for plant height, in C_2 for green weight plant^{-1} and in C_1 for stick weight plant^{-1}. This indicated that additive gene effects were important in the expression of all the traits studied. This finding correlated with the findings of Sengupta et al. (2010) regarding additive gene action for basal diameter, fibre yield, fibre tenacity and fibre fineness and Kumar et al. (2002) for green weight and stick weight. Hence these traits which hold the fixable component of the variance are likely to be more responsive to direct selection (Fouad, 2020).

The additive genetic effect (d) had a negative value for all the three crosses C_1, C_2 and C_3 in all the traits under present study except C_2 for fibre percentage and C_1 for fibre tenacity, which further indicated that for the respective traits, the lower performing parents were selected

as P_1 and higher performing parents were selected as P_2. The findings of a previous study had indicated that the positive or negative direction of additive and dominance effect signified that the parent had the highest number of positive alleles which contributed to an enhancement in the trait (Parihar et al., 2016).

The dominance component (h) was significant for fibre yield and its components and quality traits in most of the crosses suggesting the importance of dominance gene effects in the expression of all these traits (Table 3). Among the interaction components, the additive×additive (i) effect was significant and also its magnitude was higher than the additive×dominance (j) effect in C_2 and C_3 for plant height, in C_1 for basal diameter, in C_1 and C_3 for green weight plant^{-1}, in C_3 for stick weight, in C_2 for fibre percentage, in C_1, C_2 and C_3 for fibre yield plant^{-1}, in C_1 and C_2 for fibre tenacity and in C_1 and C_3 for fibre fineness.

Exception however, was for plant height in C_1 and C_2, basal diameter in C_2 and C_3, green weight plant^{-1} in C_2 and stick weight plant^{-1} and fibre percentage in both C_1 and C_3. This indicated that both additive and dominance gene effects were equally important for the inheritance of the traits supporting the earlier observations of Das and Rakshit (1989) for plant height, basal diameter and fibre yield and Palve and Kumar (1991) for plant height, fibre percentage, fibre yield and fibre tenacity. It was also found that dominance component was mostly higher in magnitude than additive component and was with negative sign in most of the crosses for majority of the traits, indicating decreased expression of traits by dominance and therefore, selection would be effective during later generation only.

Among epistatic gene effects, additive×additive (i) type epistasis was significant and important in all the three crosses for green weight plant^{-1}, fibre yield plant^{-1}, fibre tenacity and fibre fineness whereas it was significant in two of the crosses for plant height and it was significant in single cross for basal diameter, stick weight plant^{-1} and fibre percentage (Table 3). But these were mostly with positive sign indicating more scope of improvement through simple line selection only. Additive×dominance (j) type interaction was found to be non-significant in all the three crosses for all the traits studied. Dominance×Dominance (l) gene interaction was significant in all the three crosses for fibre yield plant^{-1}, fibre tenacity and fibre fineness. These findings indicate that in addition to additive and dominance gene effects, the epistatic effect were also important in the expression of the traits studied which corroborated with the findings of Eunus and Salam (1969). The higher magnitude of estimates of (l) as compared to (i) and (j) suggest the predominant role of dominance×dominance gene interaction for fibre yield and its components and quality traits.

On observation of the sign of (h) and (l) to be in opposite direction, it was possible to identify the nature of epistasis as duplicate in majority of the crosses (Lal et al., 2013), for most of the yield components and quality traits studied (Table 3). The duplicate type of epistasis was prevalent in the cross C_1 for basal diameter, green weight plant^{-1}, fibre yield plant^{-1}, fibre tenacity and fibre fineness; in the cross C_2 for stick weight plant^{-1}, fibre percentage, fibre yield plant^{-1}, fibre tenacity and fibre fineness and in the cross C_3 for plant height, green weight plant^{-1}, fibre percentage, fibre yield plant^{-1}, fibre tenacity and fibre fineness. The duplicate type of epistasis was found operative in all the three crosses for fibre yield plant^{-1}, fibre tenacity and fibre fineness. On contrary, complementary gene effect was recorded in none of the crosses for any of the traits studied. Duplicate epistasis as observed in most of the crosses for majority of the traits might result in decreased variation in F_2 and subsequent generations, might decrease heterosis and also hindered the pace of progress through selection. Duplicate type of epistasis for plant height and basal diameter was reported by Basak and Dana (1971). The present study indicated that additive, dominance and epistatic gene effects contributed significantly to the inheritance of various fibre yield and quality traits studied in tossa jute. Therefore, few cycles of recurrent selection followed by pedigree method might be effective and useful to utilize all the three types of gene effects. It might lead to increased variability in later generations for effective selection by maintaining considerable heterozygosity through mating of selected plants in early segregating generations.

The joint scaling tests (Table 4) combined the whole set of scaling tests into one and thus offered a more informative approach. The significance of the χ^2 test in all the three crosses for all the traits studied except basal diameter in cross C_3 corroborated with the findings of the scaling test proposed by Mather (1949). Therefore, the joint scaling test confirmed the inadequacy of the additive dominance model in most of the crosses for majority of the traits and indicated the presence of epistasis. It was observed in the present study that the hybrid (F_1) outperformed the better parent in the cross C_1 for plant height, basal diameter, fibre percentage and fibre yield plant^{-1}, in C_2 for basal diameter and fibre tenacity and in C_3 for plant height, fibre percentage, fibre yield plant^{-1} and fibre tenacity, which implied that there was possibility of significant better parent heterosis (heterobeltiosis), which further emphasized the preponderance of non-additive components.

Table 4: χ^2 test between observed and expected means of different generations for fibre yield components and quality traits as per "Joint Scaling Test" proposed by Cavalli (1952)

Character	C_1 (OIJ 015×JRO 878)		C_2 (OIN 574×JRO 620)		C_3 (OIN 580×JRO 128)	
	χ^2 value	Epistasis	χ^2 value	Epistasis	χ^2 value	Epistasis
Plant height (cm)	87.35**	Present	97.40**	Present	207.21**	Present
Basal diameter (mm)	68.88**	Present	84.47**	Present	5.49	Absent
Green weight plant^{-1} (g)	118.95**	Present	83.85**	Present	47.44**	Present
Stick weight plant^{-1} (g)	48.72**	Present	268.80**	Present	101.58**	Present
Fibre percentage	421.24**	Present	99.72**	Present	16.53**	Present
Fibre yield plant^{-1} (g)	184.06**	Present	171.21**	Present	52.81**	Present
Fibre tenacity (g tex^{-1})	16392.62**	Present	7875.63**	Present	1388.34**	Present
Fibre Fineness (tex)	1545.94**	Present	1974.41**	Present	1833.74**	Present

** significant ($p \leq 0.01$)

4. CONCLUSION

The present study assured the limited existence of additive dominance model as exhibited in most of the crosses for majority of the traits. Joint scaling test revealed a significant additive ×additive and dominance×dominance (I) type epistatis in all three crosses for fibre yield plant^{-1}, fibre tenacity and fibre fineness. Hence, pedigree method of conventional breeding with delayed selection will be rewarding in further jute crop improvement programme to simultaneously improve both fibre yield and quality.

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