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Research Article

Identification of best combiners and heterotic crosses for seedling characters in jute (*Corchorus olitorius* L.) under normal and drought conditions

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Abstract
Line × tester design was employed to evaluate nine parents of *Corchorus olitorius* for their combining ability and heterosis of seedling traits under normal and drought conditions. Analysis of variance revealed significant differences among the parents and their crosses. Under drought conditions, root length, fresh and dry weight of roots, and under normal conditions, root volume, shoot fresh and dry weight exhibited significant contributions to the line × tester interaction to hybrid. Among the parents, JRO 3690 and OIN 970 displayed the best GCA for seedling traits, except for root and shoot traits, both under normal and drought conditions. Specifically, JRO 3690 showed significant GCA effects for seven physiological seedling traits. Significant SCA effects, high *per se* performance, and strong heterotic effects were observed in crosses such as JRO 3690 × OIN791, JRO 8432 × OIN 791, and OIJ 214 × OEX 29 under normal conditions. Similarly, under drought conditions, crosses like JRO 632 × OIN791, JRO 524 × OIN791, and JRO 524 × OIJ177 exhibited tolerance to moisture stress condition. These identified crosses hold substantial breeding value and could be directly utilized to exploit heterosis.

Keywords: Combining ability, GCA, SCA, heterosis, tossa jute, *olitorius*, drought

INTRODUCTION

Jute, often referred to as the "Golden Fibre of Bengal," is cultivated primarily using two species, namely *Corchorus capsularis* and *Corchorus olitorius*. These species are predominantly grown in India and Bangladesh, but cultivation also takes place in China, Nepal, Indonesia, Thailand, and Myanmar. The primary distinction between the two species lies in their fibre quality and yield. The *olitorius* species produces finer, softer, stronger, and more lustrous fibres compared to the *capsularis* species. The *capsularis* fibre is typically whitish, hence earning the name "white jute." On the other hand, the *olitorius* fibre exhibits yellowish, reddish, or greyish hues, depending on the retting water used during processing (Kundu *et al*., 1951), commonly known as "tossa jute". The demand for jute fibres is currently on the rise due to the context of global warming. Additionally, the completely biodegradable, recyclable, and eco-friendly nature of jute fibres makes them versatile for a wide range of applications, including jute bags, shopping and handbags, floor coverings, decorations, fashion accessories, geotextiles, composites, and reinforcements. In India, approximately 90% of the jute cultivation area is dedicated to tossa jute, primarily due to its higher fibre yield and superior quality when compared to *capsularis* jute (Yumnam *et al*., 2015). Under drought conditions, jute seed and seedling metabolism are significantly affected. Studies by Rahman *et al*. (2021) and Dhar *et al*. (2018) have shown that seedling germination and establishment play a crucial role in crop stand. The strength of a seedling is evident from its root penetration. It has been observed that white jute performs better under waterlogged conditions of soil during its early stage of growth, while tossa jute is better suited to drought regimes (Prodhan *et al*., 2001). Therefore, studying root behaviour and early-stage crop growth becomes crucial in drought stress breeding programs aimed at identifying drought-resistant genotypes. Apart from root behaviour, leaf area development and relative water content can also serve as indicators of jute plants' potential to withstand drought situations. Inadequate water supply not only affects jute physiology but also impacts biochemical processes. For instance, proline accumulation increases gradually with decreasing water potential, and the concentration decreases once the stress is relieved (El Moukhtari *et al*., 2020). Developing jute varieties poses challenges due to limited genetic diversity and strong sexual barriers between the two cultivated species (Yumnam *et al*., 2016, Das and Kumar, 2016). Understanding the nature of inheritance, yield potential, and specific combining abilities of parents becomes crucial for establishing successful breeding programs. Mating designs, such as line × tester analysis, have been employed to evaluate the breeding value of parents. This analysis provides insights into general combining ability (GCA) and specific combining ability (SCA) effects, aiding in the identification of superior parental lines and cross combinations (Sawarkar *et al*., 2023). However, limited research has been conducted on jute fibre yield and its components under drought conditions using combining ability analysis. Therefore, considering the aforementioned factors, this study aims to investigate combining ability in tossa jute, the nature and magnitude of gene actions, and the estimation of GCA, SCA, and genetic parameters desirable under drought situations.

MATERIALS AND METHODS

The experiment was conducted at the Instructional Farm, Bidhan Chandra Krishi Viswavidyalaya, Jaguli, West Bengal, to assess the performance of jute genotypes under two distinct environmental conditions. These conditions were artificially created in earthen pots, representing i) fully irrigated and ii) drought stress conditions. The study followed a line x tester design, involving a selection of nine parents based on their distinction on their yield-contributing and drought resistance traits. The chosen parents included OEX 29, OIJ 177, OIN 791, JRO 524, JRO 632, JRO 3690, JRO 8432, OIJ 214, and OIN 970. Among the selected parents, OEX 29, OIJ 177, and OIN 791 were utilized as testers due to their favourable seedling and yield traits observed in laboratory, earthen pots, and field conditions. These testers exhibited enhanced resistance under drought conditions, displaying high tolerance indices. On the other hand, JRO 524, JRO 632, JRO 3690, JRO 8432, OIJ 214, and OIN 970 lines were identified as more susceptible to drought stress, particularly concerning low tolerance indices and formed a distinct cluster within the study.

Eighteen F_1's along with their parents were sown in earthen pots (25 cm base, 30 cm top diameter and 35 cm height) with three replications. Replication comprised of nine pots each F1 and its associated parents (line and Tester). Each three pot contained a single seed of F1 and both parents (1+1+1=3pots). This had been done three times for each cross. (3 x 3 = 9 pots/cross).Thus, for one replication, there were 9 x 18=162 pots for eighteen F1's and their parents. The pots were filled with soil mixed with FYM and fertilizers recommended as basal dose. After 21 days of sowing, the data was recorded such as root length (cm), root volume (cc), fresh and dry weight of roots, shoots and leaves and shoot length. Heterosis of each was calculated based on Parents vs. Crosses, sum of squares by partitioning the sum of squares of the genotype to its components. The general combining ability (GCA) variance of parents and the specific combining ability (SCA) variance of hybrids were estimated via line × tester variance analysis according to Singh and Chaudhary (1985). The better parent heterosis (BP) were calculated by Hallauer *et al.* (2010). All these statistical analysis were performed with the help of WINDOSTAT version 9.2 (INDOSTAT service).

RESULTS AND DISCUSSION

Analysis of variance (**Table 1**) revealed significant differences for all the seedling traits among all the entries, parents, hybrid and parent vs hybrid in both drought and normal conditions except root length and root volume for parent vs hybrid under normal condition. Lines (female parents) and testers (male parents) showed non-significant variation under both the conditions for all the seedlings characters indicating within lines or within testers there was no significant variation. Line × tester interaction showed significant variations for all the characters in both conditions. Similar findings were observed by Ali *et al*. (2014) and De Abreu *et al*. (2019). The significance of parents and hybrids for all the characters under both conditions indicated wider genetic differences among parents and as a consequence of which divergent hybrids were produced. The significant variance due to parent vs hybrid for all the characters except root length

Table 1. Analysis of variance of different seedling traits of F_1 generation along with 9 parents of *C. olitorius* under normal and drought condition in pot

Sources of variation	d.f.	Root length (cm)		Root volume (cc)		Root fresh weight (g)		Root dry weight (g)		Shoot length (cm)	
		N	D	N	D	N	D	N	D	N	D
Replication	2	0.007460	0.086	0.000005	0.00001	0.000033	0.000025	0.000004	0.0000017	0.208561	1.499
Genotypes	26	0.5169***	6.0561***	0.000035***	0.00036***	0.000125***	0.00060***	0.0000197***	0.00006***	13.6335***	34.8783***
Parents (P)	8	0.4240***	12.7001***	0.000062***	0.00089***	0.000047***	0.00078***	0.0000073***	0.00008***	3.4533***	76.2784***
P vs H	1	0.0071	28.5701***	0.00000012	0.00043***	0.000405***	0.00508***	0.0000593***	0.00056***	158.7742***	5.5767***
Hybrids(H)	17	0.590593***	1.605***	0.000024***	0.00011***	0.000145***	0.000257***	0.000023***	0.0000272***	9.886414***	17.119***
L effect	5	1.202708	0.854	0.000015	0.00021	0.000327	0.000396	0.000051	0.0000432	11.322294	6.809
T effect	2	0.150459	2.524	0.000054	0.00004	0.000027	0.000069	0.000003	0.0000074	0.914983	31.445
L X T effect	10	0.372562***	1.797***	0.000022***	0.00007***	0.000077***	0.000226***	0.000013***	0.0000231***	10.962759***	19.410***
Error	34	0.041472	0.036	0.000002	0.000001	0.000013	0.000011	0.000001	0.0000011	0.886826	0.505

*Significant at 5% probability level, ** Significant at 1% probability level, *** Significant at 0.1% probability level, N = Normal, D = Drought

Table1. Continued...

Sources of variation	d.f.	Shoot fresh weight (g)		Shoot dry weight (g)		Leaf fresh weight (g)		Leaf dry weight (g)	
		N	D	N	D	N	D	N	D
Replication	2	0.000028	0.00013	0.000003	0.000015	0.000142	0.00009	0.000014	0.000013
Genotypes	26	0.0026***	0.0016***	0.00046***	0.00022***	0.00051***	0.0071***	0.00005***	0.00079***
Parents (P)	8	0.0037***	0.0016***	0.00066***	0.00022***	0.00048***	0.0113***	0.00005***	0.00127***
P vs H	1	0.0004*	0.0059***	0.00007*	0.00076***	0.00152***	0.0208***	0.00017***	0.00233***
Hybrids(H)	17	0.002174***	0.00135***	0.000383***	0.000183***	0.000465***	0.00426***	0.000049***	0.000476***
L effect	5	0.003039	0.00232	0.000538	0.000320	0.000642	0.00635	0.000069	0.000705
T effect	2	0.000024	0.00046	0.000004	0.000065	0.000751	0.00223	0.000076	0.000249
L X T effect	10	0.002172***	0.00104***	0.000381***	0.000138***	0.000319***	0.00362***	0.000034***	0.000406***
Error	34	0.000097	0.00005	0.000017	0.000006	0.000060	0.00004	0.000006	0.000005

*Significant at 5% probability level,** Significant at 1% probability level, *** Significant at 0.1% probability level, N = Normal, D = Drought

and root volume revealed that the differential parental combinations developed heterotic hybrids for all these traits. Absence of non-significant variances for lines and testers indicated that within lines or testers there was no variation for all these characters in two water regimes. But line × testers showed significant variances for all the seedlings traits in two different moisture regimes and it could be suggested that heterosis in hybrids was the resultant effect of predominant non additive gene action.
The expressions of each trait is shown in **Table 2** in the form of contribution of line, tester and interaction between them. The contributions were much affected by their growing condition. The higher contribution of females to hybrids were observed for root length, root fresh and dry weight and leaf fresh and dry weight under normal environment and root volume and shoot fresh and dry weight under drought. The contribution of root characteristics in drought regime was revealed as some lines had the tolerant property against drought condition. Generally, under dry conditions of cultivation, deep root penetration is the sign of drought resistance. (Sawarkar *et al*., 2016). Contribution of line × tester interaction to the hybrids was high for shoot length in both water regimes and root volume, shoot fresh and dry weight in normal while root length, root fresh and dry weight and leaf fresh and dry weight in drought.

The GCA and SCA variance play an important role deciding the inheritance of the traits. The different genetic variances from line × tester design for seedling traits are represented in **Table 3**. Under normal environment, root length, root fresh weight, root dry weight, fresh and dry weight of leaf showed significant GCA as well as SCA variances which indicated the role of both additive and non-additive gene action, while root volume, shoot length, fresh and dry weight of shoot showed only significant SCA variance which suggested that the traits were controlled by non-additive gene action. The magnitude of SCA variances was found higher than the GCA variances for root length, fresh and dry weight of root indicating predominantly controlled by non-additive gene action in expression of these traits. In case of fresh and dry weight of leaf GCA variances were higher and this could be due to preponderance of additive gene action on expression of these characters. Whereas, under drought environment, significant SCA variances were found in all the seedling characters and only significant GCA variances was highlighted in root volume. Expression of most of the

Table 2. Genetic variance from Line X Tester analysis for different seedling traits of *C. olitorius* under normal and drought condition in pot

Sources of variation	Root length (cm)		Root volume (cc)		Root fresh weight (g)		Root dry weight (g)	
	N	D	N	D	N	D	N	D
σ^2gca	0.047*	0.123	0.000002	0.00001*	0.00001*	0.00002	0.000002*	0.000002
σ^2sca	0.111***	0.589***	0.00001***	0.00002***	0.00002***	0.00007***	0.000004***	0.00001***
σ^2A	0.095	0.246	0.000005	0.00002	0.00002	0.00003	0.000004	0.000004
σ^2D	0.111	0.589	0.00001	0.00002	0.00002	0.00007	0.000004	0.00001
h^2 % (N.S.)	43.229	29.084	39.138	42.741	48.908	30.443	46.668	31.924
σ^2A/ σ^2D	0.849	0.417	0.715	0.769	1.123	0.458	0.981	0.489
$\frac{\sigma_A^2}{\sigma_A^2+\sigma_D^2}$	0.459	0.294	0.417	0.435	0.529	0.314	0.495	0.328

Table 2. Continued…

Sources of variation	Shoot length (cm)		Shoot fresh weight (g)		Shoot dry weight (g)		Leaf fresh weight (g)		Leaf dry weight (g)	
	N	D	N	D	N	D	N	D	N	D
σ^2gca	0.390	1.381	0.0001	0.00010	0.00002	0.000014	0.00005*	0.00032	0.000005*	0.000035
σ^2sca	3.371***	6.309***	0.0007***	0.00033***	0.0001***	0.000044***	0.0001***	0.00119***	0.00001***	0.000134***
σ^2A	0.781	2.762	0.0002	0.00020	0.00004	0.000028	0.0001	0.00063	0.00001	0.000070
σ^2D	3.371	6.309	0.0007	0.00033	0.0001	0.000044	0.0001	0.00119	0.00001	0.000134
h^2 % (N.S.)	17.600	29.921	22.782	36.689	22.983	37.487	47.168	34.343	46.549	34.085
σ^2A/ σ^2D	0.232	0.438	0.308	0.605	0.311	0.625	1.085	0.528	1.050	0.523
$\frac{\sigma_A^2}{\sigma_A^2+\sigma_D^2}$	0.188	0.304	0.235	0.377	0.237	0.385	0.520	0.346	0.512	0.343

*Significant at 5% probability level,** Significant at 1% probability level, *** Significant at 0.1% probability level, N = Normal, D = Drought

Table 3. Proportional contribution of lines, testers and their interactions to the total variance for different seedling traits of *C. olitorius* under normal and drought condition in pot

Sources	Root length (cm)		Root volume (cc)		Root fresh weight (g)		Root dry weight(g)		Shoot length (cm)		Shoot fresh weight (g)		Shoot dry weight (g)		Leaf fresh weight (g)		Leaf dry weight (g)	
	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D
Lines	59.895	15.656	18.973	56.209	66.479	45.186	65.311	46.801	33.683	11.698	41.114	50.721	41.368	51.356	40.638	43.858	41.355	43.600
Testers	2.997	18.498	26.292	4.429	2.222	3.171	1.469	3.199	1.089	21.610	0.128	4.051	0.110	4.177	19.019	6.167	18.048	6.162
Line×Tester	37.108	65.845	54.734	39.362	31.299	51.643	33.220	50.000	65.228	66.692	58.758	45.228	58.522	44.467	40.343	49.975	40.598	50.238

(N=Normal, D= Drought)

seedling characters under drought could be suggested being controlled by non-additive gene action except for root volume where predominant non additive gene action might play role. (De and Ghosh Dastidar, 1990).The general combining ability (GCA) of parents of seedling related traits under normal and drought condition in pot are presented in **Table 4.** Under normal environment JRO 3690 and OIN 970 were found to be best general combiners for all seedling characters except root volume and root fresh weight for JRO 3690 and root and shoot length, shoot fresh and dry weight for OIN 970. The tester OIJ 177 showed significant GCA for other seedling characters like root length, root volume, leaf fresh and dry weight. On the other hand under drought condition, JRO 3690 was found to be the best general combiner for seven important characters like root length, root dry weight, shoot length, shoot fresh and dry weight, shoot, leaf fresh and dry weight. It was followed by the line JRO 632 for six important characters root length, root volume, root fresh weight, root dry weight, leaf fresh weight and leaf dry weight and tester OIJ177 also showed significant GCA for six characters root length, root volume, root fresh weight, root dry weight, leaf fresh weight and leaf dry weight, and line JRO 524 was found important showing significant GCA for five characters like root fresh weight, root dry weight, shoot length, shoot fresh weight and shoot dry weight. By exploiting these significant GCA parents in a hybridization programme it could be effective to utilize the fixable components (additive) of genetic variation for the improvement of yield and yield attributing traits in jute. The desirable specific parental combinations for seedling traits are presented in **Table 5.** Significant desirable SCA effect for various seedling characters under normal environment and drought conditions were observed. Three distinct patterns like high × high, high × poor and poor × poor combination were exhibited with varying GCA effect. Under normal conditions, it was discovered that two combinations had high × high, six combinations had high × poor, and six combinations had poor × poor. While six combinations of high × high, twenty combinations of high × poor, and thirteen combinations of poor × poor were observed under the drought regime. Under normal regime, the significant positive SCA effect were observed in JRO3690 × OIN791 (high × poor), OIJ214 × OIJ177, OIN970 × OEX29 (average × high) for root length, JRO8432 × OIJ177 (poor × high), JRO524 × OEX29 (poor × poor), JRO632 × OIN791 (high × poor) for root volume, JRO524 × OIN791 (poor × average), OIJ214 × OEX29 (high × poor), JRO3690 × OEX29 (average × poor) for root fresh weight, JRO3690 × OEX29 (high × poor), OIJ214 × OEX29 (high × poor), JRO524 × OIN791 (poor × average) for root dry weight, OIN970 × OEX29(poor × poor), JRO524 × OIJ177 (poor × poor), JRO3690 × OIN791 (high × average) for shoot length, JRO8432 × OIN791 (high × average), OIJ214 × OIJ177 (poor × poor), JRO524 × OEX29 (average × average), JRO3690 × OIN791(high × average) for shoot fresh and dry weight, JRO632 × OIN791(poor x poor), OIJ214 ×

Table 4. General combining ability (gca) effects of 9 parents for different seedling traits of *C. olitorius* under normal and drought condition in pot

Parents	Root length (cm)		Root volume(cc)		Root fresh weight(g)		Root dry weight(g)		Shoot length (cm)	
Lines (gi)	N	D	N	D	N	D	N	D	N	D
JRO3690	0.157*	0.216***	0.001	0.004***	0.002	0.003**	0.001*	0.001**	2.050***	0.699**
OIJ214	0.091	-0.084	0.0003	-0.002***	0.005***	-0.011***	0.002***	-0.004***	-0.116	-0.901***
JRO524	-0.742***	-0.087	-0.001	-0.004***	-0.005***	0.006***	-0.002***	0.002***	-0.817*	1.059***
JRO8432	0.191**	-0.408***	-0.001	0.002***	-0.009***	-0.005***	-0.004***	-0.002***	0.283	-0.121
OIN970	0.124	-0.118	-0.002**	-0.007***	0.007***	0.003*	0.002***	0.001**	-0.283	-1.101***
JRO632	0.179**	0.482***	0.002***	0.006***	0.0003	0.004**	0.0001	0.001***	-1.117***	0.366
SE (gi)	0.065	0.059	0.0005	0.0005	0.001	0.001	0.0004	0.0003	0.307	0.231
Tester (gj)										
OIJ177	0.102*	0.401***	0.002***	0.001**	-0.0004	0.002**	-0.0001	0.001**	-0.217	-0.484**
OIN791	-0.026	-0.341***	-0.001*	-0.002***	0.001	-0.001	0.0004	0.000	0.233	-1.011***
OEX29	-0.076	-0.060	-0.001**	0.001	-0.001	-0.002	-0.0003	-0.001*	-0.017	1.496***
SE (gj)	0.046	0.042	0.0004	0.0003	0.001	0.001	0.0003	0.0002	0.217	0.164

Table 4. Contiued…

Parents	Shoot fresh weight (g)		Shoot dry weight(g)		Leaf fresh weight(g)		Leaf dry weight(g)	
Lines (gi)	N	D	N	D	N	D	N	D
JRO3690	0.016***	-0.00002	0.007***	-0.0001	0.011***	0.005*	0.004***	0.002*
OIJ214	-0.002	0.001	-0.001	0.0003	0.001	-0.013***	0.0002	-0.004***
JRO524	0.006	0.016***	0.003	0.006***	-0.008**	-0.018***	-0.003**	-0.006***
JRO8432	0.011**	0.007**	0.005**	0.003**	-0.006*	-0.024***	-0.002*	-0.008***
OIN970	0.004	0.006**	0.002	0.002**	0.009***	0.0004	0.003***	0.000
JRO632	-0.035***	-0.031***	-0.015**	-0.011***	-0.008**	0.049***	-0.002**	0.016***
SE (gi)	0.003	0.002	0.001	0.001	0.003	0.002	0.001	0.0007
Tester (gj)								
OIJ177	-0.001	0.002	-0.0005	0.001	0.007***	0.012***	0.002***	0.004***
OIN791	0.000	0.004*	0.00004	0.001*	-0.005*	-0.001	-0.002*	-0.001
OEX29	0.001	-0.006***	0.0004	-0.002***	-0.003	-0.010***	-0.001	-0.003***
SE (gj)	0.002	0.002	0.001	0.001	0.002	0.001	0.001	0.0005

*Significant at 5% probability level,** Significant at 1% probability level, *** Significant at 0.1% probability level, N = Normal, D = Drought

OEX29 (average × poor)) for leaf fresh and dry weight. Under drought condition, the highest significant SCA were detected in JRO8432 × OIJ177(poor × high), JRO632 × OIN791(high × poor), OIN970 × OIN791(poor × poor), JRO3690 × OIN791(high × poor), OIJ214 × OEX29 (poor × poor) for root length, OIJ214 × OEX29 (poor × average), JRO8432 × OIJ177(high × high), JRO632 × OIN791(high × poor) for root volume, JRO8432 × OIJ177(poor × high), JRO632 × OIN791(high × poor), JRO524 × OIN791(high × poor), OIJ214 × OEX29 (poor × poor) for root fresh weight, JRO8432 × OIJ177(poor × high), JRO632 × OIN791(high x average), OIJ214 × OEX29(poor × poor) for root dry weight, JRO3690 × OEX29 (high × high), JRO8432 × OIJ177 (poor × poor), OIN970 × OEX29 (poor × high), JRO632 × OIN791 (average × poor), OIJ214 × OIN791(poor × poor) for shoot length,JRO524 × OIJ177 (average × poor), JRO632 × OIN791 (poor × high), JRO524 × OEX29 (high × poor) for shoot fresh and dry weight, JRO8432 × OIJ177(poor × high), OIN970 × OEX29 (average × poor), JRO3690 × OIN791(high x poor), OIJ214 × OIJ177 (poor × high) for leaf fresh and dry weight. From SCA estimation, it has been cleared the GCA effect of the parents need not necessarily determine the desirable SCA effect of each cross combination. The high SCA effect of these crosses may be due to the complementary type of gene action. The SCA effect is a crucial indicator of the utility of a particular cross combination for the exploitation of heterosis (Peng and Virmani, 1990). The combination of a desirable SCA effect involving both parents and a favourable GCA

Table 5. Specific combining ability (sca) effects of F1 hybrids for different seedling traits of *C. olitorius* under normal and drought condition in pot

Hybrids	Root length (cm)		Root volume (cc)		Root fresh weight (g)		Root dry weight (g)		Shoot length (cm)		Shoot fresh weight (g)		Shoot dry weight (g)		Leaf fresh weight (g)		Leaf dry weight (g)	
	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D
JRO3690 X OIJ177	-0.202	0.133	-0.003**	0.002	-0.005*	0.005*	-0.002**	0.002*	-0.917	-2.882***	-0.010	-0.001	-0.004	-0.001	0.009*	-0.013***	0.003*	-0.004**
JRO3690 X OIN791	0.426***	0.574***	0.001	-0.004***	-0.00004	0.002	0.000	0.0004	1.333*	-0.855*	0.026***	0.004	0.011***	0.001	0.002	0.036***	0.001	0.012***
JRO3690 X OEX29	-0.224	-0.707***	0.002*	0.002*	0.005*	-0.007***	0.002**	-0.002**	-0.417	3.738***	-0.016**	-0.002	-0.007**	-0.001	-0.012**	-0.023***	-0.004*	-0.008***
OIJ214 X OIJ177	0.365**	-0.168	0.002	-0.008***	-0.002	-0.008***	-0.001	-0.003***	0.150	-0.982*	0.032***	0.003	0.014***	0.001	-0.005	0.025***	-0.002	0.008***
OIJ214 X OIN791	-0.507***	-0.225*	-0.001	0.001	-0.003	0.003	-0.001*	0.001	-0.700	1.445***	-0.021***	-0.002	-0.009***	-0.001	-0.007	-0.018***	-0.002	-0.006***
OIJ214 X OEX29	0.142	0.393***	-0.001	0.007***	0.005*	0.005**	0.002**	0.002**	0.550	-0.462	-0.011	-0.001	-0.005*	-0.0001	0.012**	-0.006	0.004**	-0.002
JRO524 X OIJ177	0.098	0.047	-0.001	0.002*	-0.001	-0.003	-0.0003	-0.001	2.650***	2.558***	0.003	0.025***	0.001	0.009***	0.002	-0.012***	0.001	-0.004**
JRO524 X OIN791	-0.274*	-0.123	-0.002	-0.001	0.006**	0.005**	0.002**	0.002**	0.200	-1.215**	-0.034***	-0.039***	-0.014***	-0.014***	-0.007	0.007*	-0.002	0.003*
JRO524 X OEX29	0.176	0.076	0.003**	-0.001	-0.005**	-0.002	-0.002**	-0.001	-2.850***	-1.342**	0.031***	0.014***	0.013***	0.005***	0.005	0.005	0.001	0.001
JRO8432 X OIJ177	0.165	0.757***	0.004***	0.006***	0.004	0.012***	0.001*	0.004***	-0.550	3.038***	-0.022***	-0.011**	-0.009***	-0.004**	0.009	0.051***	0.003*	0.017***
JRO8432 X OIN791	0.192	-1.542***	-0.001	-0.003**	0.003	-0.016***	0.001	-0.005***	0.700	-0.896*	0.038***	0.008*	0.016***	0.003*	-0.004	-0.035***	-0.001	-0.012***
JRO8432 X OEX29	-0.358**	0.785***	-0.003***	-0.003**	-0.007**	0.004*	-0.003***	0.001*	-0.150	-2.142***	-0.016**	0.002	-0.007**	0.001	-0.005	-0.016***	-0.002	-0.005***
OIN970 X OIJ177	-0.368**	-0.334**	0.002	0.002*	0.003	0.001	0.001*	0.0003	-1.783**	-1.982***	-0.007	-0.002	-0.003	-0.001	-0.005	-0.051***	-0.002	-0.017***
OIN970 X OIN791	0.059	0.608***	-0.001	0.002*	-0.005*	-0.002	-0.002**	-0.001	-1.533**	-0.056	-0.004	0.006	-0.002	0.002	0.000	0.006	0.000	0.002
OIN970 X OEX29	0.309**	-0.274*	-0.0005	-0.004***	0.002	0.001	0.001	0.001	3.317***	2.038***	0.011*	-0.005	0.005*	-0.002	0.006	0.045***	0.002	0.015***
JRO632 X OIJ177	-0.058	-0.434***	-0.003**	-0.003**	0.001	-0.007***	0.0001	-0.002***	0.450	0.251	0.004	-0.015***	0.002	-0.005***	-0.009*	0.001	-0.003*	0.0001
JRO632 X OIN791	0.104	0.708***	0.003**	0.004***	-0.0005	0.009***	-0.0001	0.003***	0.000	1.578***	-0.004	0.023***	-0.002	0.008***	0.015**	0.004	0.005**	0.001
JRO632 X OEX29	-0.046	-0.273*	0.0002	-0.001	-0.0001	-0.002	0.000	-0.001	-0.450	-1.829***	0.0003	-0.008*	0.0002	-0.003*	-0.006	-0.005	-0.002	-0.002
SE(ij)	0.113	0.102	0.001	0.001	0.002	0.002	0.001	0.001	0.532	0.401	0.005	0.004	0.002	0.001	0.004	0.003	0.001	0.001

*Significant at 5% probability level,** Significant at 1% probability level, *** Significant at 0.1% probability level, N = Normal, D = Drought

effect suggests an additive x additive effect, and simple selection can be rewarded for improvements. The interaction between the dominant allele from a good combiner and the recessive allele from a poor combiner may be responsible for the favourable performance of combination with parents with high and low GCA effects. (Dubey, 1975). According to Singh *et al*. (1973), when a parent with a highly desirable GCA effect is crossed with another parent that has a poor GCA effect, the resulting offspring can exhibit transgressive segregation. This can lead to the emergence of new populations, provided that the additive genetic system in the good combiner and the epistatic effect in the crosses complement each other to maximize desirable plant traits. These traits can then be further utilized for breeding purposes. If crosses involving one good and one poor combiner, or both poor combiners as parents, exhibit positive significant SCA effects, it suggests that genetic divergence of the parents involved in the crosses and balanced gene complexes are important. This balanced gene complex is associated with a low degree of inbreeding depression. From the result high SCA effect involving poor x high, high x poor and high x average general combiners may be exploited for the development of pure line through pedigree breeding. Similar results were also reported by Kumar *et al*. (2011) and De and Ghosh Dastidar (1990).

Best three crosses with their mean, SCA, GCA and heterosis in normal and drought condition are shown in **Table 6 and Table 7**. Under normal condition, significant heterotic effects were observed for various traits. Specifically, JRO3690 x OIN791 exhibited a significant heterotic effect on root length, while the cross between JRO8432 x OIJ177, as well as JRO524 x OEX29, showed significant effects on root volume. Additionally, OIJ214 x OEX29 displayed a significant heterotic effect on root fresh and dry weight, and JRO8432 x OIN791 exhibited such an effect on shoot fresh weight. Moreover, JRO3690 x OIN791 demonstrated a significant heterotic effect on shoot dry weight, and JRO3690 x OIJ177 displayed such an effect on leaf fresh and dry weight. To achieve a high, consistent, and stable heterotic effect in jute, it is crucial to ensure the presence of appropriate gene content in the homozygous state, where suitable alleles are entirely dominant without influencing the performance of the heterozygote. This requirement contributes to the desired heterotic effect, uniformity, and stability in jute. Under drought conditions, the best heterotic effect was observed in only three traits. Specifically, JRO632 x OIN791 exhibited a significant heterotic effect on root fresh weight, JRO524 x OIN791 revealed such an effect on root dry weight, and JRO524 x OIJ177 indicated significant effects on shoot fresh and dry weight. In both normal and drought

Table 6. Best three crosses and their mean, SCA, GCA, heterosis status of line x tester design of *C. olitorius* under normal condition in pot

Traits	Best crosses	Mean	SCA	GCA status	Heterosis
Root length (cm)	JRO3690XOIN791	8.500	0.426***	HXP	4.930*
	OIJ214XOIJ177	8.500	0.365**	AXH	-
	OIN970XOEX29	8.300	0.309*	AXH	-
Root volume (cc)	JRO8432XOIJ177	0.069	0.004***	PXH	6.150**
	JRO632XOIN791	0.068	0.003**	HXP	-
	JRO524XOEX29	0.065	0.003**	PXP	5.410*
Root fresh weight (g)	JRO524XOIN791	0.138	0.006*	PXA	-
	OIJ214XOEX29	0.154	0.005*	HXP	8.450**
	JRO3690XOEX29	0.151	0.005*	AXP	-
Root dry weight (g)	JRO524XOIN791	0.052	0.002**	PXA	-
	JRO3690XOEX29	0.054	0.002**	HXP	-
	OIJ214XOEX29	0.055	0.002**	HXP	9.330**
Shoot length (cm)	OIN970XOEX29	36.800	3.317***	PXP	-
	JRO524XOIJ177	38.300	2.650***	PXP	-5.200**
	JRO3690XOIN791	40.300	1.333**	HXA	-
Shoot fresh weight (g)	JRO8432XOIN791	0.435	0.038***	HXA	9.400**
	OIJ214XOIJ177	0.415	0.032***	PXP	-
	JRO524XOEX29	0.425	0.031***	AXA	-
Shoot dry weight (g)	JRO8432XOIN791	0.154	0.016***	HXA	9.330**
	OIJ214XOIJ177	0.172	0.014***	PXP	-
	JRO3690XOIN791	0.177	0.011***	AXP	12.980
Leaf fresh weight (g)	JRO632XOIN791	0.327	0.015**	PXP	-
	OIJ214XOEX29	0.334	0.012**	AXP	-
	JRO3690XOIJ177	0.351	0.009*	PXH	3.850*
Leaf dry weight (g)	OIJ214XOEX29	0.106	0.004**	AXP	-
	JRO3690XOIJ177	0.111	0.003*	HXP	4.050*
	JRO8432XOIJ177	0.106	0.003*	PXP	-

*Significant at 5% probability level,** Significant at 1% probability level, *** Significant at 0.1% probability (A= Average, P= Poor, H= High)

Table 7. Best three crosses and their mean, SCA, GCA, heterosis status of line x tester design of *C. olitorius* under drought condition in pot

Traits	Best crosses	Mean	SCA	GCA status	Heterosis
Root length (cm)	JRO8432×OEX29	8.068	0.785***	P×P	-14.170**
	JRO8432×OIJ177	8.500	0.752***	P×H	-7.610**
	JRO632×OIN791	8.600	0.708***	H×P	-4.440**
Root volume (cc)	OIJ214×OEX29	0.067	0.005**	P×A	-12.990**
	JRO8432×OIJ177	0.070	0.006**	H×H	-6.670**
	JRO632×OIN791	0.070	0.004***	H×P	-17.650**
Root fresh weight (g)	JRO8432×OIJ177	0.146	0.012***	P×H	-
	JRO632×OIN791	0.148	0.009***	H×P	3.730*
	OIJ214×OEX29	0.130	0.005**	P×P	-6.710**
Root dry weight (g)	JRO8432×OIJ177	0.045	0.004***	P×H	3.880*
	JRO632×OIN791	0.045	0.003***	H×A	3.820*
	JRO524×OIN791	0.046	0.002**	H×A	4.580*
Shoot length (cm)	JRO3690×OEX29	35.700	3.738***	H×H	-7.030**
	JRO8432×OIJ177	32.200	3.038***	P×P	-11.050**
	JRO524×OIJ177	32.900	2.558***	H×P	-9.120**
Shoot fresh weight (g)	JRO524×OIJ177	0.335	0.025***	P×H	13.180**
	JRO632×OIN791	0.288	0.023***	H×P	-
	JRO8432×OIN791	0.311	0.008*	H×H	6.140**
Shoot dry weight (g)	JRO524×OIJ177	0.121	0.009***	H×P	13.440**
	JRO632×OIN791	0.103	0.008***	P×H	-
	JRO524×OEX29	0.114	0.005***	H×P	-8.120**
Leaf fresh weight (g)	JRO8432×OIJ177	0.285	0.051***	P×A	-
	OIN970×OEX29	0.281	0.045***	P×H	-3.770*
	JRO3690×OIN791	0.286	0.036***	A×H	-3.380*
Leaf dry weight (g)	JRO8432×OIJ177	0.105	0.017***	P×A	-
	OIN970×OEX29	0.103	0.015***	P×H	-
	JRO3690×OIN791	0.105	0.012***	P×H	-3.380*

*Significant at 5% probability level,** Significant at 1% probability level, *** Significant at 0.1% probability (A= Average, P= Poor, H= High)

conditions, these crosses exhibited high significant SCA effects, along with notable performance for the respective traits. In the context of drought stress, the tolerance of jute plants towards root and shoot characteristics in the early stages of growth becomes highly significant for their subsequent development. Notably, a deep root system serves as a strong indicator of drought tolerance. Therefore, in drought stress conditions, the development of potential heterotic hybrids with desirable root and shoot traits in *olitorius* jute holds great significance in achieving increased fibre yield while ensuring drought tolerance.

Therefore, the crosses JRO632 × OIN791, JRO524 × OIN791 and JRO524 × OIJ177 have substantial value of breeding, could be directly used to exploit heterosis to confirm their behaviour by extending the experiment and evaluate the performance in the field under drought conditions.

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