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Potential and Genetic Basis of Drought Tolerance in Canola *(Brassica napus)*: I. Generation Mean Analysis for Some Phenological and Yield Components

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ABSTRACT

Analysis of generation means viz., P_1, P_2, F_1, F_2, BC_1, and BC_2 of three crosses of *Brassica napus i.e.* Range x Shiralee, Range x Ester and Rainbow x Ester was performed under irrigation and drought conditions to determine the nature of gene action governing yield and yield components. Type of gene action varied with the plant traits, crosses and treatments. Genotype x environment interaction was statistically significant in the expression of all the plant traits. Number of components of generation means varied with crosses and treatments. Both additive and non-additive gene action was involved in most of the traits in different crosses under the two treatments. But majority of the traits were under non-additive control, having the duplicate or complementary type of epistasis. Dominance for oil contents was towards higher value. Plant height, days to first bud, days to maturity were found to be controlled by four to five parameter models, showing that these traits were controlled by more than two genes acting in a complex fashion.

Key Words: *Brassica napus*; Generation Mean Analysis; Gene Action; Irrigation; Drought; Oil contents; Phenology; yield components

INTRODUCTION

The climate of Pakistan predominantly is arid to semi-arid showing general deficiency of water for potential crop production. It is estimated that $1/4^{th}$ of the total cultivated land (4.9 millions hectares) is drought prone (Khan & Qayyum, 1986) and much of the area is under threat because of the silting up of the water reservoirs. The situation urges to breed crop cultivars that need little water for potential production. Pakistan is suffering from chronic deficit of edible oil and to meet the domestic needs has to depend on import, which requires huge amounts of hard earned foreign exchange amounting Rs. 38.08 billions (Govt. of Pakistan, 2002-03). Because, in Pakistan Brassica is grown under varied environmental conditions and mostly under arid and semi-arid environment therefore, could serve model crop that can help cultivate water deficit areas. For a successful breeding programme the availability of genetic variability and the knowledge of gene action operating to impart drought tolerance are essential and the dearth of which breeding methods used may not result in appreciable improvement. A series of experiments were performed to synthesize the drought tolerant breeding material and to furnish the scientific knowledge on type of gene action. The present paper presents the information on type of gene action for yield and yield components under normal and drought condition in three brassica crosses.

A great deal of variability is present in the breeding material, its response to drought and in genotype environment interaction. Rishipal and Kumar (1993) reported that environment and crosses in *Brassica juncea* considerably influenced the gene effects. Additive and non-additive effects governed the expression of number of primary branches, seeds/siliquae, 1000-seed weight and seed yield, the latter being the most important. A duplicate type of epistasis was observed for most traits. Yadav *et al.* (1993) found that simple selection under both normal and late-sown conditions would improve 1000-seed weight, while selection for yield and number of secondary branches would be more effective under normal sowing conditions only.

Dominance and epistasis effects of the gene action for days to first flower, plant height, siliquae/plant and yield/plant were found in different generations by Singh and Singh (1994) where as non-additive gene action appeared to be predominant for all traits except days to maturity, which was governed by additive gene action (Patel *et al*., 1996). In Indian mustard (*B. juncea)* preponderance of non-additive gene action was found for most traits including oil content (Sheikh & Singh, 1998) and additive genetic variance was more important for plant height. Presence of both additive and non-additive gene effects in controlling the expression of various traits and predominant presence of non-additive gene action was found to control the yield *in B. juncea* (Khuble *et. al.*, 1998).

The preponderance of duplicate gene action is indicative of the possibility of improvement through heterosis breeding (Celine & Sirohi, 1998). Plant height in brassica displayed low genetic advance irrespective of their high heritability estimates, probably due to non-additive gene effects i.e., dominance and epistasis (Larik & Rajput, 2000). On the basis of selection indices, it could be concluded that branches per plant and siliquae per plant had been the most important yield components. Days to flowering were predominantly governed by a non-additive gene action in Indian mustard (*B. juncea*). However both additive and non-additive gene action types were important in the inheritance of most of the traits studied (Tak & Khan, 2000). Predominant role of non-additive gene action along with over dominance for number of days to flowering and maturity length of main raceme, number of secondary branches, yield per plant, test weight and oil content. Non-additive gene effects controlled the yield per plant (Prasad *et al*., 2001).

A predominance of non-additive component for a majority of the yield contributing traits including plant height in *B. juncea is* suggested by Rao and Gulati (2001), whereas in pigeon pea additive gene effects controlled days to 50% flowering and days to maturity, plant height and 100-seed weight (Hooda *et al*., 2000). Ghosh *et al.* (2002) were of the opinion that for most of the major traits including seed yield had both additive and non-additive gene action of prime importance in Indian mustard. Such variability of results indicated clearly that the inheritance patterns of plant traits imparting drought tolerance and yield varies with the genetic material and the climatic vagaries that suggested exploring the genetic information about the present material before performing selection.

MATERIALS AND METHODS

The experiments were conducted in the experimental area of the Department of Plant Breeding and Genetics at Postgraduate Agricultural Research Station (PARS), University of Agriculture Faisalabad during the year 1999-2002. The experimental material comprised of sixteen generations of *Brassicas napus* including four parents. Two, drought tolerant i.e., Shiralee and Range and two drought susceptible accessions Ester and Rainbow were the parent lines and their selection was based on reports of (Sadaqat 1999).

Synthesis of generations. Parental lines were planted in pots during September 1999 and hybridisation through hand emasculations and controlled pollinations was done at the time of flowering during January and February 2000 in following fashion.

1. Drought tolerance x drought tolerance (Range x Shiralee) i.e. (T x T)
2. Drought susceptible x drought susceptible (Rainbow x Ester) i.e. (S x S)
3. Drought tolerance x drought susceptible (Range x Ester) i.e. (T x S)

Apart of the seeds of F_1 hybrids so obtained was sown in the field to develop other generations. Some of the F_1 plants in each cross were selfed to obtain F_2, and the others were used in back crossing to obtain BC_1 and BC_2 generations through hand emasculations and controlled pollinations. BC_1 and BC_2 are the crosses of F_1 hybrids with parent 1 and parent 2 respectively. The hybridization programme of the above stated 4 parental lines thus yielded 12 generations.

Experimental lay out. The field experiment was laid out in a triplicate Factorial Randomized Complete Block Design. The experimental material was sown under normal and drought conditions in the field during the last week of September 2001. The fertilizer inputs i.e. one bag of DAP and half bag of urea per acre were applied to both the treatments at the time of sowing. Row to row distance of 45 cm, and plant to plant distance of 15 cm were maintained by thinning out plants at early four-leaf stage in every experimental plot with row length of 20 meter. A single row for parental and F_1 generations, two rows for each back cross and three for F_2 generations were planted. In case of normal condition three irrigations were applied while in drought conditions no irrigation was applied except for land preparation. Crop was sprayed to control the aphid at the time of flowering by using insecticide advantage @ 500 ml/acre. During the field experiments soil moisture, air temperature, air humidity, and rainfall were recorded (Fig. I). When crop was at vegetative phase, 30 plants in parents and F_1 and 90 plants in segregating generation were tagged to record data on various plant traits.

Data recording. At maturity the plant height was measured in centimeters from the ground level to the tip of the plant including inflorescence with the help of a meter rod. The branches having origin from main stem and the branches having origin from primary branches were counted at maturity for number of primary and secondary branches per plant. Total number of siliquae obtained from a plant was regarded as siliquae/plant.

Days were counted from the sowing time to the appearance of the first flower as days to first flower and to the day when plants had turned brown as days to maturity. Reproductive period was calculate as *Reproductive Stage = Days to maturity - Days to flower initiation*. Harvest index was calculated as *Harvest index = Seed yield/Dry stem straw*. Total quantity of seeds obtained from each tagged plant was weighed and recorded as seed yield per plant. Seed oil contents were determined using NMR.

Biometrical approaches. Analysis of variance was performed using the GLM procedures of SAS software. The generation means analysis (Mather & Jinks, 1982) was performed using statistical software developed by Dr. Pooni, Birmingham University UK.

RESULTS

Analysis of variance revealed significant (P = 0.05-0.001) differences among treatments, i.e. normal and drought and generations, (P_1, P_2, F_1, F_2, BC_1 & BC_2) for various morphological viz. yield/plant, siliquae/plant, plant height, primary branches, secondary branches, harvest index, days to first bud, days to maturity and reproductive period (Table I). Generation and treatment interaction terms were similarly significant for all the above-mentioned traits. Coefficients of variability were high in yield, siliquae/plant, primary branches and secondary branches, moderate in harvest index, plant height, days to first bud and reproductive period comparatively low in other plant traits.

Analysis of variance presented in (Table II) indicated that various generations have significant difference for all the morphological traits and oil contents under both normal and drought conditions. Variability associated with various traits in terms of coefficients of variability was increased in drought conditions compared with normal condition in plant height, primary branches/plant, secondary branches/plant and yield, whereas variability coefficients were reduced for all other traits and oil contents.

Four to five parameter model was found fit for plant height (Tables III, IV). Dominance component was much higher (5-7 times) than additive component. Dominance was not detected in Range x Ester (TxS) and Range x Shiralee (TxT) under normal and drought condition respectively. Additive component in Range x Shiralee (TxT) and Rainbow x Ester (SxS) was higher under normal condition than drought. Additive component was higher in Range x Shiralee (TxT) under normal conditions (Table III) whereas under drought higher additive component was found in Range x Ester (TxS). Generally (h) and (l) had positive signs. Highest mean was found in Rainbow x Ester (SxS) under normal and Range x Shiralee (TxT) under drought (Table IV). Two to five parameters model was found to be the most fitted in different crosses under normal and drought to explain the primary branches per plant (Tables III, IV).

Three to five parameter model was found fit for secondary branches under both conditions (Table III, IV). Additive, dominance and all three types of interactions were found associated with genetic control of secondary branches. Dominance component was higher than additive in almost all crosses under both treatments except in Rainbow x Ester (SxS) under drought, where it could not be detected. Different interaction varied with crosses and treatment. Components of generation means for number of siliquae/plant presented in (Tables III, IV) showed very high value of dominance compared to additive effects that indicated predominance role of non-additive type of gene action. The presence of interaction along with higher dominant values also indicated presence of over dominance. However, in most of instance, positive sign of (h) indicates that dominance is towards the higher parents.

The value of (h) was absent in case of some crosses under normal as well as drought conditions. It might be due to bi-directional nature of additive x dominance interaction in Range x Shiralee (TxT) cross under normal and drought condition. In Rainbow x Ester (SxS) dominance was

Table I. Mean squares and their significance from analysis of variance of pooled data for various morphological traits

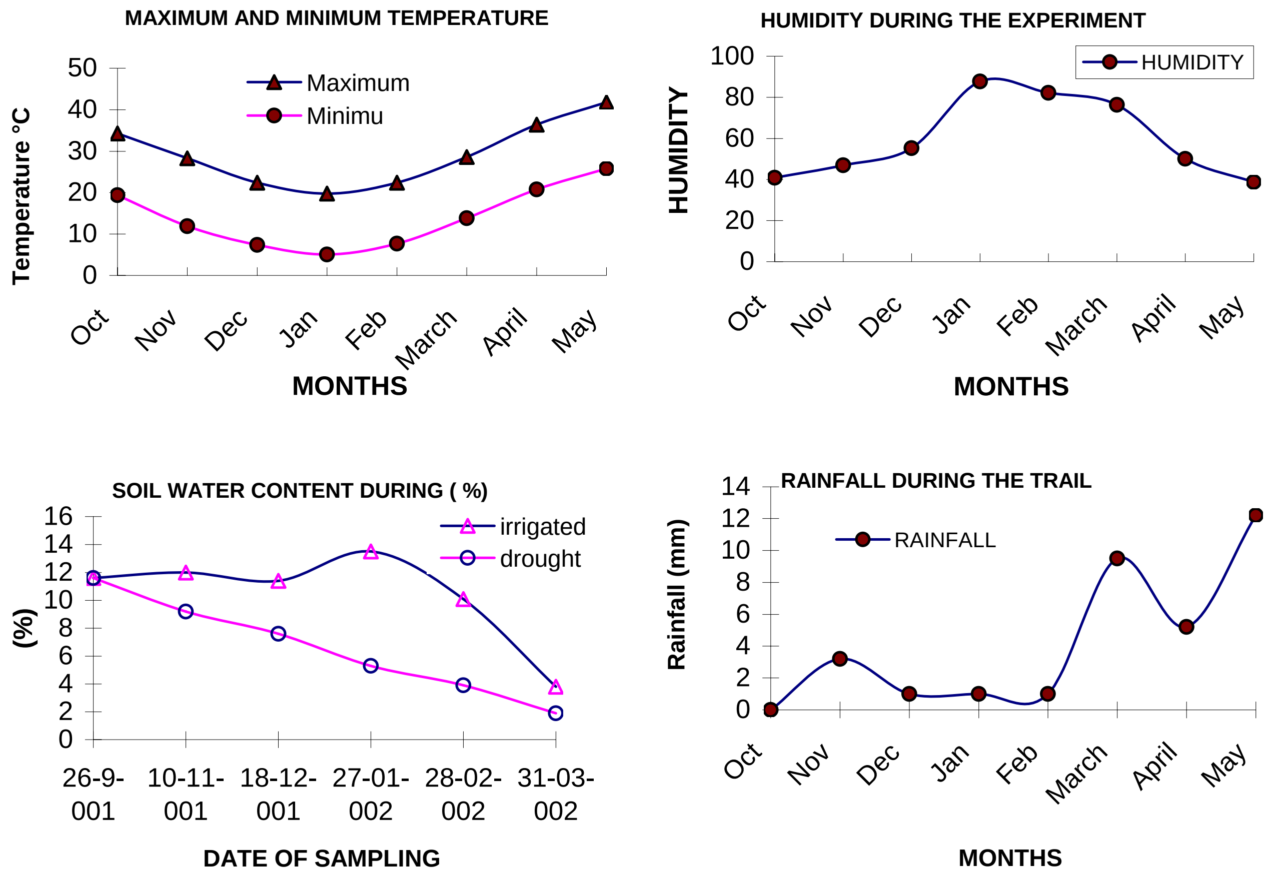
Traits	Rep	GEN.	TR.	GEN. X TR.	E. M.S	C.V.%
Plant height	11945.24***	11099.45***	252791.46***	3563.83***	507.98	15.21
Primary branches	37.022	114.37***	5054.40***	129.75***	12.01	39.75
Secondary branches	142.38*	414.29**	23460.28***	227.50***	32.27	48.39
Siliquae/plant	58494.23	291974.20***	2636579.49***	102719.50***	25266.24	40.69
Days to first bud	1447.49***	2277.51***	48246.43***	1007.09***	67.48	9.63
Days to maturity	123.32*	2746.87***	61805.31***	440.44***	22.56	2.56
Reproductive periods	2394.17***	788.74***	1660.05***	1015.90***	89.45	9.47
Harvest index	1164.77***	337.27***	77511.93***	687.90***	55.15	25.49
Yield	196.43	8.59.92***	19687.86***	197.95***	67.36	46.56

Table II. Mean squares and their significances from analysis of variances of various morphological traits under normal and drought conditions

Traits	Normal				Drought			
	GEN.	REP.	E.M.S	C.V%	GEN.	REP.	E.M.S	C.V%
Plant height	6092.64***	8096.83***	507.95	14.05	8570.64***	13190.58***	486.52	16.23
Primary branches	218.73***	55.41	16.11	38.40	25.39***	89.39***	7.67	39.67
Secondary branches	491.34**	5.24	41.06	41.40	150.45***	306.55***	23.14	60.11
Siliquae/plant	217234.23***	115301.06	31129.10	41.00	177459.47***	12681.03	19295.79	39.57
Days to first bud	2055.55***	69.26	76.59	9.65	1229.05***	2787.54***	55.11	9.29
Days to maturity	1445.91***	5.85	28.30	2.77	1741.40***	209.70***	16.66	2. 28
Reproductive period	667.21***	54.18	95.91	9.70	1137.44***	4323.81	78.38	8.95
Harvest index	238.82***	443.39***	48.52	31.18	786.35***	859.01***	61.58	21.84
Yield	753.14***	261.67	85.52	43.93	304.73***	77.97	49.02	49.30
Oil content	12.31***	4.72	2.82	4.96	14.28***	5.57	2.82	4.73

*Significant at P = 0.05; ** Significant at P = 0.01; *** Significant at P = 0.001; Rep.= Replication; GEN = Generation; TR. = Treatment; E.M.S = Error Mean Square

Fig. 1. Meteorological data during the experiment at Faisalabad, Pakistan



detected; yet dominance x dominance interaction had higher value than additive effect.

Four to six parameter model was fit for explaining variation in days to first bud in different crosses under both treatments in present material of canola (Tables III, IV). Additive, dominance and all type of interactions components were found. Dominance component was not found in Range x Shiralee (TxT) under normal as well as drought condition. Dominance component where ever present were higher than additive, but not detected in Rainbow x Ester (SxS) under both treatments and Range x Ester (TxS) under normal. Dominance x dominance interaction was not detected in Range x Shiralee (TxT) under normal and Rainbow x Ester (SxS) under drought condition.

Four to five parameters model was found fit to explain the variation in days to maturity (Tables III, IV). Dominance estimate was not detect in Range x Shiralee (TxT) and Range x Ester (TxS) under normal condition. In all other crosses dominance component was higher than additive one. Additive x additive interaction term had negative sign in Range x Shiralee (TxT) under normal and positive sign in Rainbow x Ester (SxS), and Range x Ester (TxS)

Dominance x dominance interaction was estimated in all crosses under both treatments except for Range x Shiralee (TxT) under normal condition (Table III).

Component of generation mean indicated three to five parameter model fit for explaining the variation in harvest index (Tables III, IV). Additive x dominance and non-allelic interaction were responsible for expression of harvest index under normal and drought conditions. Dominance component was much higher than additive component. Dominance was in the order of Range x Shiralee (TxT), Rainbow x Ester (SxS) and Range x Ester (TxS) under normal, whereas under drought, the order was reverse. Dominance component was not detected in Rainbow x Ester (SxS) under normal and Range x Ester (TxS) under drought condition. Components of generation mean provided in (Tables III, IV) indicated that number of parameters were variable two treatments. Significant additive effects were present in almost all cross viz. Range x Shiralee (TxT), Rainbow x Ester (SxS) and Range x Ester (TxS) in both treatment conditions. The magnitude of additive affects varied with the parents of crosses and treatments. Additive

Table III. Gene effects for morphological traits under irrigated condition in three crosses of canola

					Irrigated					
Traits	**Crosses**	**m**	**d**	**h**	**i**	**j**	**l**	**X^2**	**p**	**F**
P. H	TXT SXS	130.62±2.69	13.94±2.76	96.17±6.82		14.95±5.91	-62.8±5.9			
	TXS	165.45±1.78	4.92±1.80	-30.9±5.4		-25.4±4.9	13.12±5.52	1.12	1	0.9-0.1
		154.31±1.57	6.17±2.57		- 15.1±6.2		22.45±6.63	1.13	1	
								0.382	1	
P.B	TXT SXS	7.84±0.34	1.93±0.39	3.94±0.60		-5.1±0.74	-5.8±1.0	0.79	2	0.9-0.1
	TXS	2.63±1.44	1.03±0.47	17.26±2.32	6.62±1.55		-4.3±0.8	0.05	1	
		7.40±0.36	0.89±0.37	6.95±0.95		7.4±0.93		1.8	1	
S.B	TXT SXS	6.7±1.3	4.4±0.8	13.4±1.7	6.4±1.5	-8.14±1.1	-10.0±1.6	0.12	1	0.9-0.1
	TXS	6.1±2.0	1.9±0.4	21.1±3.4	8.3±2.0		-6.6±1.6	0.54	1	
		10.6±0.5	1.9±0.5	10.9±1.7		9.7±1.7		0.10	1	
Silq /pl	TXT SXS	234.5±50.0	85.35±16.9	393.1±67.7	208.3±53.9	-99.8±36.8		6.6	1	0.01-
	TXS	419.7±8.3	26.2±10.1				36.1±11.3	7.8	3	0.005
		425.0±5.5	16.7±8.3		-56.5±10.2			7.2	3	0.05
										0.1-0.05
D. F.B.	TXT SXS	86.9±0.7	3.08±0.9		-8.7±1.2	-10.85±1.9		8.6	2	0.025-
	TXS	95.5±0.8	2.32±0.7	-4.55±2.14			8.4±1.6	7.1	2	0.01
		86.5±0.8	11.5±0.8	13.6±2.3			-5.3±2.0	0.05	1	0.050-
										0.025
										0.900-
										0.100
D.M	TXT SXS	186.9±0.3	0.79±0.39		-3.6±0.5	-4.7±0.9		2.5	2	0.900-
	TXS	199.3±0.4	0.94±0.38	-13.3±1.3		-7.3±1.4	11.6±1.2	9.3	1	0.100
		190.4±0.3	7.86±0.34			-16.7±1.0	9.0±0.5	9.9	2	<0.005
										0.010-
										0.005
H.I	TXT SXS	13.9±2.4	2.3±0.7	15.3±4.0	10.6±2.4		-4.0±1.9	0.25	1	0.900-
	TXS	22.3±0.4	1.9±0.6				3.1±1.0	2.25	3	0.100
		23.1±0.8	1.5±0.7	-4.0±1.4				2.01	3	
Yld / plt	TXT SXS	11.6±2.8	4.5±0.7	18.5±3.9	8.3±3.0	-7.4±2.1		4.8	1	0.050-
	TXS	6.3±2.5	3.4±0.5	28.4±4.1	10.7±2.6		-12.2±1.9	2.3	1	0.025
		14.4±0.5	0.9±0.5	11.0±1.2				4.1	3	0.9-0.1
O.C	TXT SXS	35.3±0.4	1.4±0.6				-7.12±1.02	8.5	4	0.1-0.05
	TXS	30.6±0.5	2.2±0.5	10.4±1.3			-3.0±1.5	3.8	2	0.9-0.1
		3.8±0.6	2.0±0.6	5.4±1.6				1.4	2	0.9-0.1

P.H = plant height; P.B = primery branches; S.B. = secondry branches; Silq./P = siliquae per plant; D.F.B = day for first bud; D.M = day for maturity; R.PD. = reproductive period; H.I = harvest index; YLD/PLT = yield per plant; O.L = oil content; Tolerant x Tolerant = (TXT); SuceptableXSuceptable (SXS); Tolerant Tolerant (TXS)

effect was higher under control condition than drought condition and was higher in crosses of Range x Shiralee (TxT) , than other crosses under drought conditions and in TxS under normal.

Additive x additive interaction was positive and significant in Range x Shiralee (TxT), Rainbow x Ester (SxS) under normal conditions and in Range x Ester (TxS) under drought condition whereas in Rainbow x Ester (SxS) has appeared negative.

Additive x dominance interaction was detected in Range x Shiralee (TxT) under normal and drought condition and also in Rainbow x Ester (SxS) under drought condition. In all the cases signs were negative when as dominance x dominance interaction was detected in Rainbow x Ester (SxS) with negative sign in normal and Range x Shiralee (TxT) with positive sign under drought.

Dominance component was higher than additive component for yield in canola under both treatments. Under drought condition in Rainbow x Ester (SxS) neither dominance nor dominance x dominance interaction was detected. However in this case negative interactions of additive x additive, additive x dominance were obvious.

In crosses Range x Ester (TxS) under both conditions non-additive type of interaction i.e. additive x dominance, dominance x dominance were not present.

Components of generation means presented in (Tables III, IV) revealed, relatively simple inheritance compared to other traits. Number of components varied with crosses and treatment. Dominance and epistatic component were not detected in Range x Shiralee (TxT) under both conditions. In Range x Ester (TxS), Rainbow x Ester (SxS) dominance was higher than additive component.

DISCUSSION

Generation mean components for plant height indicated the major role of non-additive type of gene action attributable to dominance and epistatic effects. Singh and Singh (1994) and Rao and Gulati, 2001 concluded similar findings as those in present studies that plant height is under the control of dominance. Larik and Rajput (2000) studied *B. juncea* and *B. napus* together and reported the

Table- IV. Gene effects for morphological traits under drought condition in three crosses of canola

					Drought					
Traits	**Crosses**	**m**	**d**	h	**i**	**j**	**l**	**X^2**	**p**	**F**
P. H		149.0±2.6	5.5±2.9		-11.5±4.3	-32.8±6.5	8.8±4.4	1.4	1	0.900-
	TXT SXS	114.1±2.2	4.4±2.1	27.7±5.9			-10.8±4.8	0.3	2	0.100
	TXS	11.5±5.5	7.3±2.0	39.7±7.4	15.2±6.3			5.1	2	0.950-
										0.900
										0.100-
										0.050
P.B	TXT SXS	4.36±0.7	0.64±0.31	4.27±1.0	2.06±0.80	-1.42±0.54		0.024	1	0.900-
	TXS	6.7±0.15	0.56±0.22			-1.3±0.6	1.6±0.4	8.98	4	0.100
		6.8±0.16	0.14±0.31					0.18	2	0.100-
										0.050
										0.950-
										0.900
S.B	TXT SXS	2.0±1.3	1.3±0.5	10.21±1.8	5.5±1.5	-4.6±1.2		0.19	1	0.900-
	TXS	7.6±0.2	0.6±0.2				3.0±1.6	8.9	3	0.100
		3.0±1.0	0.7±0.4	7.0±1.1	5.31±1.1			9.29	2	0.050-
										0.025
										0.010-
										0.005
Silq /pl	TXT SXS	127.9±34.4	52.4±10.6	365.6±41.17	243.7±36.9	-47.21±27.26		1.27	1	0.900-
	TXS	240.2±46.6	15.5±4.8	160.6±80.1	133.2±47.1	-0.80±38.82		0.004	1	0.100
		312.2±6.5	41.9±11.8		39.4±14.4			4.27	3	0.950
										0.900-
										0.100
D. F.B.	TXT SXS	74.15±0.8	2.5±0.7	2.9±1.5	3.7±1.2	-13.16±2.10	14.9±1.6	0.44	1	0.900-
	TXS	82.6±0.7	1.8±0.8	30.5±4.3		-4.0±1.4		0.87	2	0.100
		58.0±2.5	1.8±0.7		24.3±2.6		-4.9±1.9	0.02	1	
D.M	TXT SXS	169.6±0.4	1.30±0.4	4.5±1.3		-5.6±1.4	3.8±1.3	0.003	1	0.975-
	TXS	177.9±1.0	2.2±0.3	11.0±1.6	7.6±1.0		-3.4±0.9	0.48	1	0.95
		168.0±1.5	7.3±0.3	23.9±2.3	7.8±1.5		-12.7±0.9	3.8	1	0.900-
										0.100
										0.100-
										0.050
H.I	TXT SXS	30.4±2.2	1.8±0.5	8.9±3.07	7.18±2.32			4.8	2	0.100-
	TXS	27.2±1.9	2.7±1.4	6.79±2.43	7.66±2.53	-6.3±2.2		2.8	1	0.050
		39.4±0.5	3.4±0.55		-4.0±0.81	-11.0±1.6		4.5	2	0.100-
										0.050
										0.900-
										0.100
Yld / plt	TXT SXS	14.9±0.3	2.1±0.39			-10.56±1.8	14.30±0.63	9.9	2	0.010-
	TXS	13.4±0.4	1.58±0.62		-2.62±0.76	-3.650±1.34		1.7	2	0.005
		6.8±1.4	1.13±0.50	11.17±1.65	5.19±1.62			8.8	2	0.900-
										0.100
										0.025-
										0.010
O.C	TXT SXS	37.45±0.30	0.83±0.40		6.1±1.9			4.1	4	0.900-
	TXS	27.32±1.8	1.73±0.38	8.8±2.1	4.7±2.6			1.1	2	0.10
		30.31±2.5	3.11±0.4	7.5±3.0		-2.9±1.2		0.003	1	0.900-
										0.100
										0.975-
										0.950

P.H = plant height; P.B = primery branches; S.B. = secondry branches; Silq./P = siliquae per plant; D.F.B = day for first bud; D.M = day for maturity; R.PD. = reproductive period; H.I = harvest index; YLD/PLT = yield per plant; O.L = oil content; Tolerant x Tolerant = (TXT); SuceptableXSuceptable (SXS); Tolerant Tolerant (TXS)

involvement of additive effects in the phenotypic expression of the plant height, which is corroborated of the present studies. Sheikh (1998) performed the combing ability studies in *B. juncea* and observed predominance of additive effects. The differences in findings of Sheikh (1998) and those in the present studies could be related with the genetic differences in the breeding material and methodology adopted for genetic analysis.

Number of primary branches found to be governed through a complex of genes along with epistatic effects. Negative and positive sign of (l) component indicated bi-directional dominance in genes. Rao and Gulati (2001) supported these results. Rishipal and Kumar (1993) studied the inheritance patterns of yield and yield components in *B. juncea* and reported 3-6 parameter model fit for explaining the primary branches per plant and the parameters were different in different crosses and environments.

Higher value of dominance and interaction terms compared to additive component showed the pre-dominant of non-additive type of gene action capable of expressing heterotic effect attributable to over dominance or supper dominance. Rao and Gulati (2001) and Prasad *et al.* (2002) found similar result but contradictory results were concluded by Larik and Rajput (2000) that branches controlled by additive gene action. Negative sign (l) in Rainbow x Ester (SxS) and Range x Ester (TxS) indicates duplicate type of epistasis (Rishipal & Kumar,1993), and positive (h) reflects that dominance was towards higher parent, which could be exploited in plant breeding experiments having directive for higher secondary branches. Higher number of parameters indicates presence of more than two gene acting in a complex manner.

Components of generation means for siliquae/plant indicated that both additive and non-additive types were active in the control of siliquae/plant. Singh and Singh (1994) and Larik and Rajput (2000) reported involvement of additive gene action. The magnitude of (h) and/or the values of dominance and their interaction were much high than additive. However the higher magnitude of dominance and epistatic effects in TxT and Rainbow x Ester (SxS) were in collaboration with the present studies which indicated that improvement in such traits could be accomplished through reciprocal recurrent selection, or/and such crosses could be utilized in hybrid seed production.

Four to five parameter model indicated more than two genes governing days to first bud in a complex fashion. Higher dominance interaction values indicate predominance of non-additive type of gene action capable of expressing heterosis in different crosses. Similar results were concluded by Singh and Singh (1994), Celine and Sirohi (1998), Prasad *et al*. (2002) and Tak and Khan (2000). Parameter (h) was positive in most of instances, except Rainbow x Ester (SxS) showing dominance towards higher parent value, whereas reverse in Rainbow x Ester (SxS) under normal condition.

The absence of (h) as well as (l) component in cross Range x Shiralee (TxT) signify major role of additive x additive and additive x dominance interaction. Due to expressing higher additive effects, the presence of additive, dominance and interaction components demand selection in later generation. Results (Tables III, IV) revealed more than two genes along with epistatic effects governing days to maturity. The type of epistasis varied with crosses and treatment, signify that different type of gene action worked for expression of days to maturity.

Absence of dominance component in Range x Shiralee (TxT), Range x Ester (TxS) under normal condition might be attributed to the epistatic effect which suppressed the dominance. The results were supported by Khulbe *et al.*, (2000), (Rao & Gulati, 2001) and Prasad *et al*. (2002) and contrary results were found by Patel (1996) and Hooda *et al*. (2000). The contrasting sign of (l) component in cross Rainbow x Ester (SxS) under normal and drought and Range x Ester (TxS) under drought revealed duplicate type of epistasis, whereas in Range x Shiralee (TxT) under drought condition have positive sign and thus signifies the complementary type of epistasis.

The presence of comparatively higher value of interaction terms of non-fixable type along with higher dominance component indicates that different crosses have potential to express the heterosis. The high value of dominance component indicated the predominance of non-additive type of gene action, with over/super dominance in crosses Range x Shiralee (TxT) under normal Rainbow x Ester (SxS) under drought condition. Epistatic effects in crosses Rainbow x Ester (SxS) under normal and Range x Ester (TxS) under drought conditions sounds suppressing the dominance component. Highest mean was related with TxS under both conditions but dominance was not consistent (Tables III, IV). However mean related TxT under drought was close to TxS and had positive dominance, which could be exploited for the improvement of harvest index through breeding. Dominance in yield was not detected under drought condition in Range x Shiralee (TxT) and Rainbow x Ester (SxS). The presence of interaction i.e. i, j, l indicated the presence of dominance that might have been suppressed due to bi-directional nature of dominance is genes governing yield under drought. Singh and Singh (1994), Celine and Sirohi (1998), Khuble (1998), Sheikh and Singh (1998), Rao and Gulati (2001), and Prasad *et al*. (2002) supported the results of present studies.

Generation mean components for oil content (Tables III, IV) showed additive and non-additive type of gene action controlling its expression. Number of components of generation means varied with crosses and treatments. (Kant & Gulati 2000) also reported different parameters across different crosses and environments and thus their results are in agreement with the present studies. Additive components entirely were responsible for the variation in oil consents in Range x Shiralee (TxT) whereas, in other crosses additive component with dominance and epistasis (additive x additive additive x dominance and dominance x dominance) were observed in present studies. Cross Range x Shiralee (TxT) reflects the potential therefore, for direct improvement in oil contents under normal as well as drought.

CONCLUSION

It is concluded from the present studies that with the changes in environment (irrigated or drought) gene effects for different traits contributing to yield or yield itself changes. So for different environment one has to suggest different selection criteria for the improvement in the yield. For those traits that are controlled by additive gene action, simple selection in early generation is suggested, whereas for those traits controlled by non-additive gene action selection in later generation would be more effective**.**

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