Bangladesh J. Bot. **50**(2): 351-358, 2021 (June)

DETECTION OF EPISTASIS AND GENETIC PARAMETERS OF SOME QUANTITATIVE TRAITS THROUGH TRIPLE TEST CROSS ANALYSIS IN CHICKPEA (*CICER ARIETINUM* L.)

MT HASAN AND AC DEB*

Department of Genetic Engineering and Biotechnology, University of Rajshahi,
Rajshahi-6205, Bangladesh

Keywords: Epistasis, Genetic components, Direction of dominance

Abstract

Triple test cross analysis was carried out to detect the epistasis of thirteen yield and yield components in five chickpea (*Cicer arietinum* L.) crosses. Total epistatic effect was found to be non-significant for all the studied traits. Partitioning of total epistasis indicated the involvement of 'i' type (additive × additive) epistasis for DFF, PHFF, PWH, NPd/P, PdW/P, NS/P and SW/P in cross-1; NPBFF and NSBFF in cross-3 and for PHFF, DMF, PHMF and NSBMF in cross-5. The magnitude of additive component (D) was higher than that of the dominance component (H). Partial degree of dominance (√H/D) was observed for most of the traits. Both broad (h^2_b) and narrow (h^2_n) sense heritability were found to be moderately high. Positive and significant correlation between sums and differences indicated the direction of dominance towards decreasing parents and vice-versa.

Introduction

Chickpea (*Cicer arietinum* L.) is an annual legume belonging to Fabaceae and commonly known as gram, Bengal gram, garbanzo or garbanzo bean and Egyptian pea, widely grown for its nutritious seeds. The seeds are high in fibre and protein and good source of iron, phosphorus and folic acid. It also contains potentially health-beneficial phytochemicals (Wood and Grusak 2007). Chickpea dominates international markets over other legume crops and it is traditionally a low-input crop and is grown extensively in the moisture stress environments (Yadav *et al.* 2007). Thus, more importance should be given in the cropping intensity on chickpea in Bangladesh. To formulate an efficient breeding program, it is essential to understand the mode of inheritance, the magnitude of gene effects and their mode of action.

Triple Test Cross (TTC) provides precise estimates of various genetic parameters together with the availability of a test for epistasis which is not envisaged in other multiple mating designs. TTC analysis was successfully used in chickpea (Malhotra and Singh 1989) and other genotypes such as in bhendi (Saravanan *et al.* 2005), in rice (Ram *et al.* 2007), in wheat (Zafar *et al.* 2008), in lentil (Kumar *et al.* 2011, Azad 2012). Therefore, an attempt was made to examine the role of various components of genetic variance in the inheritance of yield and yield components using TTC analysis.

Materials and Methods

The experiment was conducted in the research field of the Biometrical Genetics Research Laboratory of the University of Rajshahi, Bangladesh during the crop season of 2009-2010 to 2012-2013. Five chickpea genotypes *viz.,* BARI chola-1, BARI chola-4, BARI chola-6, BARI chola-7 and BARI chola-8 were taken as research materials. These genotypes were hybridized to develop F_1 seed. From F_2 population, 10 plants were randomly selected as male and crossed back to their respective P_1,

---

*Author for correspondence: <anil_deb2001@yahoo.com>, <debac@ru.ac.bd>.

DOI: https://doi.org/10.3329/bjb.v50i2.54092

P_2 and F_1 to generate L_{1i} ($P_1 \times F_2$), L_{2i} ($P_2 \times F_2$) and L_{3i} ($F_1 \times F_2$), families as suggested by Kearsey and Jinks (1968). As a result, 30 families were obtained for each of the five separate crosses for genetic study. The experimental field layout was a randomized complete block design with three replications. Data were recorded on 13 yield and yield components *viz.*, date of first flower (DFF), plant height at first flower (PHFF), number of primary branches at first flower (NPBFF), number of secondary branches at first flower (NSBFF), date of maximum flower (DMF), plant height at maximum flower (PHMF), number of primary branches at maximum flower (NPBMF), number of secondary branches at maximum flower (NSBMF), plant weight at harvest (PWH), number of pods per plant (NPd/P), pod weight per plant (PdW/P), number of seeds per plant (NS/P) and seed weight per plant (SW/P).

Collected data were analyzed following the biometrical technique of analysis which was developed by Kearsey and Jinks (1968) as an extension of North Carolina Design III (NCD III) of Comstock and Robinson (1952).

Results and Discussion

Results of detection of epistatic effect for all the 13 characters in all the five different crosses separately are presented in Table 1. The method allows partitioning of the item total epistasis into fixable (‘i’ type i.e., additive × additive interaction) and unfixable epistasis (‘j + l’ type i.e., additive × dominance and dominance × dominance interaction) for 1 and 9 degrees of freedom, respectively. Similarly, total epiatsis × blocks was partitioned into ‘i’ type epistasis × blocks and ‘j + l’ type epistasis × blocks for 2 and 18 degrees of freedom, respectively. Before testing individual epistasis, the homogeneity of the interaction was first tested. So for homogeneity, at first ‘i’ type eplstasis × blocks was tested against ‘j + l’ type epistasis × blocks. In this study, this test was found to be non-significant for all the characters and crosses, suggesting homogeneity of interaction variances. It is therefore, items *viz.,* total epistasis, ‘i’ type epistasis, ‘j + l’ type epistasis, ‘i’ type epistasis × blocks and ‘j+l’ type epistasis × blocks in all cases were tested against total epistasis × blocks.

In the present study, total epistatic effect was found to be non-significant for all the traits which are in conformity with the study of Malhotra and Singh (1989) in chickpea and Ram *et al.* (2007) in rice. Division of total epistasis into ‘i’ (additive × additive) type epistasis and ‘j + l’ (additive × dominance and dominance × dominance) type epistasis indicated the involvement of ‘i’ type epistasis for DFF, PHFF, PWH, NPd/P, PdW/P, NS/P and SW/P in cross-1; for NPBFF and NSBFF in cross-3 and for PHFF, DMF, PHMF and NSBMF in cross-5 due to their significant values. The greater magnitude of ‘i’ type epistasis for these traits has significance in chickpea breeding where a linear directional and fixable component of genetic variation can be effectively exploited compared to non-directional and unfixable components (Ram *et al.* 2007). The influence of additive × additive type of epistasis for plant height was also reported by Verma *et al.* (2006) in rice. On the other hand, involvement of ‘j + l’ type epistasis was found for DFF in cross-2; for PHMF, NSBMF and NS/P in cross-3 and for PHFF and NSBFF in cross-4.

Obtained result revealed that ‘i’ type epistasis was higher in magnitude than ‘j + l’ type epistasis for most of the studied characters in all crosses reflecting the importance of additive × additive non-allelic interaction in the genetic system controlling such characters. The importance of additive × additive type of epistasis has been amply demonstrated by several researchers such as Hassan-Sher *et al.* (2012) and Pavan *et al.* (2017) in maize. Standard hybridization and selection procedures could take benefit of epistasis if it is ‘i’ type epistasis whereas, ‘j + l’ types of epistasis are not fixable by selection under self-fertilization and therefore they would not be favourable for developing pure lines; it could be useful in the development of hybrids only (Ketata *et al.*1976). The interaction of total, ‘i’ type and ‘j+l’ types of epistasis with blocks were non-significant which indicated that these interactions were not sensitive to the environments (blocks). These results are in agreement with the results reported by Saleem *et al.* (2009) in rice. However, most of the traits of the studied crosses showed non-significant epistatic effects indicating that there were no significant roles of epistasis in the expression of these traits. Absence of epistasis was reported by several investigators for different traits in deferent crops *viz.*, in mungbean (Khattak *et al.* 2002) and lentil (Azad 2012). The non-significant estimates of epistasis may happen due to the involvement of common alleles or the limited number of lines used or may be the environmental influences (Khattak *et al.* 2002). Therefore, more elaborate experiments as well as efficient breeding procedures are needed to get a clear picture of the genetic systems controlling these characters.

Analysis of variance for sums ($\overline{L}_{1i} + \overline{L}_{2i} + \overline{L}_{3i}$) and differences ($\overline{L}_{1i} - \overline{L}_{2i}$) provides direct tests of the significance of additive and dominance components. The ten (10) sums of means of the families provided a variance of sums with 9 degrees of freedom. Similarly, the variance of differences was also obtained with 9 degrees of freedom. Variances of sums × blocks and differences × blocks were computed each for 18 degrees of freedom. At first, the items *viz.,* sums, differences, sums × blocks and differences × blocks were tested against their respective within family error. Later on, sums and differences were also tested against sums × blocks and differences × blocks, respectively. In this way, test of significance of variance for sums and differences were done separately for all the characters and the results obtained are presented in Table 2. In this investigation, both sums (σ^2_s) and differences (σ^2_d) items were found to be significant in maximum cases when tested against within families while, in few cases when tested against their respective interaction (sums × blocks and differences × blocks item). The significant sums and differences observed in the present investigation indicated the importance of both additive and dominance variance in controlling the expression of these traits in chickpea. The significant differences indicated that L_1 and L_2 testers were different from each other. Similar results were noted by Saravanan *et al.* (2005) in bhendi, Azad (2012) in lentil.

The results of additive ($\hat{D}$) and dominance ($\hat{H}$) components of variation, degree of dominance ($\sqrt{H/D}$), heritability in narrow sense (h^2_n) and broad sense (h^2_b) with direction of dominance ($r_{s.d}$) for all crosses and characters are presented in Table 3. The results showed the magnitude of additive component of variation was higher than that of dominance component of variation for most of the traits in each cross which indicated the presence of common alleles in the testers and their cumulative effects in the expression of the traits which can be improved by pedigree method of selection. Again, a high magnitude of additive variance for respective characters indicated the relative importance of fixable type of gene action in their inheritance. These results are in conformity with the findings of Kumar *et al.* (2011) in lentil. Additive values are expected to be higher in self-pollinated crops like chickpea but the environment may influence the gene action. In respect of degree of dominance ($\sqrt{H/D}$), partial dominance was found for most of the traits in each cross which indicated the predominant nature of additive genetic component. Similar results were reported by Zafar *et al.* (2008) in wheat and by Kumar *et al.* (2011) in lentil. High narrow sense heritability was noted for PHMF and NSBMF in cross-1; for DFF, NSBFF, DMF and PWH in cross-2; for DFF, PHFF and NSBMF in cross-3; only for PHMF in cross-4 and for DFF, PHMF and NPBMF in cross-5. The high estimates of narrow sense heritability indicate the characters are largely governed by additive genes and hence these characters will be improved through the simple selection procedure. Furthermore, the broad sense heritability was higher than narrow sense heritability in almost all the crosses for all the characters, as would be expected. Similar findings were reported by Khan and McNeilly (2005) in maize.

Table 1. MS value of analysis of variance for epistasis ($\bar{L}_{1i} + \bar{L}_{2i} - 2\bar{L}_{3i}$) for 13 characters of five crosses in chickpea.

Source	df	Cross	DFF	PHFF	NPBFF	NSBFF	DMF	PHMF	NPBMF	NSBMF	PWH	NPd/P	PdW/P	NS/P	SW/P
Total	10	1	77.71	42.17	0.25	0.74	26.14	43.45	0.90	6.34	2233.08	1218.11	101.95	2076.55	70.53
Epistasis		2	45.09	69.96	0.33	0.92	24.23	47.76	1.94	5.09	912.82	1365.13	126.64	1394.64	68.14
		3	30.59	29.65	0.71	0.90	11.75	48.81	0.94	4.31	2175.68	2796.87	233.97	5207.85	117.07
		4	54.77	24.14	046	1.94	13.83	139.29	0.64	7.36	4097.74	3437.95	179.67	2166.01	145.13
		5	32.79	50.68	0.64	1.52	63.11	110.06	1.27	4.13	1107.13	4604.50	321.98	7908.58	202.40
i type	1	1	404.80**	114.07*	0.01	1.12	38.08	51.53	1.12	6.16	5288.09*	5264.22**	448.22*	10319.36**	314.38*
epistasis		2	6.53	139.88	2.02	0.02	33.28	25.76	0.80	0.64	388.36	3456.13	616.35	6026.50	293.28
		3	1.72	52.90	1.63*	2.35*	7.10	5.58	1.28	0.38	2493.40	1657.63	58.24	1218.58	27.45
		4	84.67	0.38	0.19	0.64	11.04	83.86	0.01	14.42	6290.11	5707.68	495.64	5647.15	181.74
		5	12.03	158.97*	1.04	1.63	404.80*	248.02*	0.14	14.70*	1349.38	11579.74	930.98	8676.80	841.21
j+l type	9	1	41.37	34.18	0.28	0.70	24.81	42.55	0.88	6.36	1893.64	768.54	63.48	1160.68	40.44
epistasis		2	49.38*	62.19	0.14	1.02	23.23	50.20	2.06	5.59	971.09	1132.80	72.23	879.99	43.12
		3	33.80	27.07	0.60	0.74	12.26	53.62*	0.91	4.75*	2140.38	2923.46	253.49	5651.10*	127.03
		4	51.45	26.78*	0.49	2.09*	14.14	145.44	0.71	6.57	3854.15	3185.75	144.56	1779.22	141.06
		5	35.10	38.65	0.60	1.51	25.15	94.73	1.39	2.96	1080.22	3829.47	254.37	7823.22	131.42
Total	20	1	36.99	18.72	0.47	0.94	19.22	59.06	0.90	3.59	1052.40	641.05	98.48	1167.78	48.53
epistasis		2	19.96	34.94	0.54	0.74	37.91	48.02	1.54	2.69	1094.88	894.81	146.76	2162.75	70.44
×		3	18.13	13.26	0.30	0.53	14.59	21.16	0.51	1.85	1083.58	1993.11	120.37	2315.17	65.75
Blocks		4	24.30	10.79	0.33	0.86	12.31	65.06	0.55	3.59	2710.74	1514.69	127.12	1346.10	62.51
		5	24.29	29.83	0.36	0.67	67.09	47.38	0.60	2.75	2066.10	2720.04	228.46	5677.34	198.65
i type	2	1	78.77	25.14	0.30	0.54	8.87	40.40	0.88	4.34	1782.34	905.85	100.14	1734.59	63.71
×		2	1.47	25.38	0.93	0.64	6.11	23.13	1.34	0.30	1144.90	873.89	156.53	1917.00	54.36
Blocks		3	3.09	14.42	0.29	0.77	18.86	24.09	0.22	0.52	904.36	1600.49	135.60	2817.99	116.50
		4	21.51	11.89	0.73	0.63	2.09	42.37	1.41	3.80	1898.01	2580.48	201.06	2854.16	152.96
		5	42.99	41.59	0.68	1.14	121.03	56.84	0.09	3.28	5525.78	4279.42	629.93	8938.32	545.16
j+l type	18	1	32.35	18.00	0.49	0.99	20.37	61.13	0.91	3.51	971.30	611.62	98.36	1104.80	46.84
×		2	22.01	36.00	0.50	0.76	41.44	50.79	1.56	2.96	1089.32	897.13	145.67	2190.05	72.23
Blocks		3	19.80	13.13	0.31	0.50	14.11	20.84	0.54	1.99	1103.50	2036.74	118.68	2259.30	60.12
		4	24.61	10.67	0.29	0.88	13.44	67.59	0.45	3.57	2801.04	1396.27	118.90	1178.53	52.46
		5	22.22	28.52	0.33	0.62	61.09	46.32	0.65	2.69	1681.70	2546.78	183.86	5315.01	160.14

* and ** indicate significant at 5% and 1% level, respectively.

Table 2. Analysis of variance for sums ($\overline{L}_{1i} + \overline{L}_{2i} + \overline{L}_{3i}$) and differences ($\overline{L}_{1i} - \overline{L}_{2i}$) for 13 characters of five crosses in chickpea.

Source	df	Cross	DFF	PHFF	NPBFF	NSBFF	DMF	PHMF	NPBMF	NSBMF	PWH	NPd/P	PdW/P	NS/P	S W/P
Sums	9	1	97.18	45.94**	0.46	0.69	67.35*	243.84**	0.72	7.86**	2665.76**	1202.83*	174.76*	3119.74*	92.91
($\overline{L}_{1i} + \overline{L}_{2i} + \overline{L}_{3i}$)		2	107.10	50.14	0.31	0.35	138.95	58.34	1.82	8.66	5042.46**	2543.82	361.47	4957.71*	216.36*
		3	122.38**	33.70**	0.33	1.05	51.89	71.71	0.63	8.47**	1292.82	2343.16	271.14	3789.38	195.83
		4	13.99	19.34*	0.33	0.72	31.54	25.16	0.37	3.59	2900.87*	1434.51	178.97	1857.05	142.42
		5	97.56*	24.15	0.39	1.04	24.41	32.08	2.80**	2.53	2015.54	7310.93*	685.06*	20451.77*	504.81*
Sums	18	1	43.07	10.85	0.22	0.59	20.87	60.81	0.37	1.27	441.54	449.99	64.96	1053.54	45.27
×		2	47.04	24.75	0.14	1.84	62.03	48.81	1.18	3.61	1367.11	1465.90	149.96	1618.83	85.80
blocks		3	13.04	5.89	0.23	0.76	25.36	76.16	0.50	1.81	607.80	1909.35	206.95	2424.21	101.97
		4	7.74	7.77	0.15	0.45	17.94	59.32	0.43	1.48	2466.21	1330.23	171.46	1019.47	93.94
		5	29.07	15.02	0.38	0.65	15.13	69.69	0.44	1.44	2314.51	2887.12	270.82	7674.36	155.16
Within families	360	1	7.87	5.86	0.09	0.29	6.75	13.96	0.16	0.58	284.41	155.60	19.23	297.11	11.72
		2	7.23	8.28	0.08	0.23	7.29	9.97	0.17	0.79	398.70	422.03	44.76	570.26	27.79
		3	7.17	3.13	0.10	0.21	4.25	10.22	0.15	0.77	293.96	324.64	28.38	435.75	16.19
		4	3.94	3.19	0.07	0.19	3.95	7.68	0.09	0.98	665.58	341.41	37.61	402.88	19.32
		5	7.18	4.15	0.13	0.34	9.33	8.88	0.18	1.06	478.28	949.86	70.22	2242.58	42.44
Differences	9	1	34.58*	21.72*	0.13	0.31	17.60*	22.08	0.09	0.64	1608.14*	890.59**	88.11**	1895.81**	75.57**
($\overline{L}_{1i} - \overline{L}_{2i}$)		2	15.67	14.33	0.24	0.28	6.20	15.35	0.30	2.57*	1333.93*	947.61	119.34	1750.48	67.76
		3	76.40**	4.04*	0.15	0.59	11.14	43.51*	0.43*	1.33	439.74	325.19	48.82	776.04	35.99
		4	13.46	9.58	0.27	0.28	6.21	36.65	0.15	3.59**	1837.01	686.32	51.99	489.67	23.70
		5	45.72**	7.12	0.03	1.24*	30.04**	29.77*	0.50**	1.17	1080.80	1283.45	90.31	2687.57	40.15
Differences ×	18	1	12.31	6.27	0.12	0.31	5.30	18.25	0.14	0.93	461.38	145.01	19.75	315.45	13.43
blocks		2	6.57	11.55	0.24	0.37	24.55	14.27	0.16	1.02	409.69	866.89	78.02	1017.90	42.20
		3	10.61	1.61	0.18	0.36	9.35	15.04	0.17	0.64	284.62	391.12	40.97	759.95	27.31
		4	5.50	7.04	0.14	0.20	5.85	18.09	0.18	0.16	1165.88	447.74	44.56	408.25	22.15
		5	11.79	3.57	0.16	0.38	8.22	9.02	0.11	2.86	1204.66	1574.23	157.15	4232.78	89.15
Within families	240	1	8.93	6.00	0.09	0.31	7.91	17.90	0.15	0.57	288.80	167.15	20.13	339.59	12.53
		2	8.67	10.23	0.09	0.25	9.19	10.84	0.20	0.86	451.69	482.02	47.62	646.99	30.04
		3	8.74	3.41	0.09	0.23	5.10	12.83	0.16	0.69	280.62	360.49	31.23	501.62	19.13
		4	3.87	3.11	0.07	0.19	4.20	8.05	0.09	1.04	861.07	440.86	49.79	471.40	24.83
		5	8.68	4.52	0.12	0.34	9.91	7.67	0.22	1.09	592.62	1361.69	106.27	3248.26	64.20

* and ** indicate significant at 5% and 1% level, respectively.

Table 3. Estimates of additive ($\hat{D}$) and dominance ($\hat{H}$) components of variation, degree of dominance ($\sqrt{H/D}$), heritability (h^2_n & h^2_b) and direction of dominance ($r_{s.d}$) for 13 characters of five crosses in chickpea.

Source	Cross	DFF	PHFF	NPBFF	NSBFF	DMF	PHMF	NPBMF	NSBMF	PWH	NPd/P	PdW/P	NS/P	S W/P
$\hat{D}$	1	14.47±1.41	9.35±1.13	0.06±0.12	0.02±0.23	12.39±1.36	48.80±2.87	0.09±0.20	1.75±0.32	566.45±7.32	200.75±5.88	29.27±2.14	550.98±8.72	12.70±1.61
	2	16.01±1.63	6.77±1.08	0.04±0.09	-0.39±0.20	20.51±1.89	2.54±1.65	0.17±0.21	1.34±0.41	980.09±9.08	287.44±10.77	56.40±3.69	890.36±12.30	34.81±2.92
	3	29.15±1.24	7.41±0.69	0.02±0.09	0.07±0.16	7.07±1.28	-1.18±1.86	0.03±0.14	1.77± 0.36	182.67± 5.79	115.68± 8.03	17.18± 2.67	364.04± 9.45	25.02±2.05
	4	1.66±0.65	3.08±0.68	0.04±0.10	0.07±0.15	3.62±0.87	-9.10±1.36	-0.01±0.14	0.56±0.38	115.91±11.10	27.80±7.47	2.00±2.74	223.35±6.78	12.92±2.04
	5	18.26±1.34	2.43±0.76	0.01±0.11	0.10±0.17	2.47±0.98	-10.02±1.68	0.63±0.20	0.29±0.25	-79.72±9.33	1179.68±17.92	110.46±5.20	3407.30±27.92	93.23±4.13
$\hat{H}$	1	8.91±0.79	6.17±0.68	0.01±0.06	-0.01±0.12	4.91±0.58	1.53±1.05	-0.01±0.07	-0.11±0.16	458.70±5.42	298.23±3.63	27.34±1.20	632.14±5.42	24.85±1.07
	2	3.64±0.61	1.11±0.62	0.01±0.09	-0.03±0.10	-7.34±0.77	0.43±0.73	0.05±0.08	0.62±0.23	369.69±4.73	32.28±6.63	16.52±2.12	293.03±7.73	10.22±1.64
	3	26.31±1.00	0.97±0.28	-0.01±0.07	0.09±0.12	0.73±0.57	11.38±1.05	0.10±0.09	0.27± 0.16	62.04± 3.30	-26.37± 3.50	3.14± 1.23	6.43± 5.26	3.47± 1.01
	4	3.18±0.53	1.01±0.49	0.04±0.08	0.03±0.09	0.43±0.14	7.42±0.87	-0.01±0.07	1.37±0.20	268.45±6.95	95.43±4.52	2.97±1.28	32.56±4.19	0.61±0.98
	5	13.57±0.87	1.42±0.46	-0.04±0.07	0.34±0.14	8.72±0.82	8.29±0.80	0.15±0.09	-0.67±0.27	-49.54±6.26	-116.31±7.18	-26.73±2.06	-618.08±10.84	-19.53±1.51
$\sqrt{H/D}$	1	0.7891	0.8110	0.2402	-0.2714	0.6269	0.1811	-0.4380	-0.2582	0.9010	1.2212	0.9701	1.0702	1.4010
	2	0.4812	0.4014	0.1952	0.3121	-0.5982	0.4014	0.5714	0.6874	0.6112	0.3414	0.5410	0.5701	0.5401
	3	0.9431	0.3612	-0.7511	1.1012	0.3210	-3.0976	1.7323	0.3912	0.5753	-0.4682	0.4310	0.1312	0.3711
	4	1.3812	0.5710	1.0101	0.6945	0.2012	-0.9028	0.9112	1.5614	1.5212	1.8512	1.2211	0.3810	0.2210
	5	0.8621	0.7612	-4.7871	1.8210	1.8812	-0.9097	0.4924	-1.5171	0.7914	-0.3140	-0.4920	-0.4259	-0.4577
h^2n	1	0.4568	0.4539	0.2538	0.0409	0.4797	0.6697	0.2444	0.7008	0.4919	0.3617	0.4244	0.4423	0.3099
	2	0.5366	0.2595	0.1848	-1.7027	0.5858	0.1042	0.3195	0.4602	0.5690	0.2273	0.3817	0.4221	0.3818
	3	0.6297	0.6043	0.1159	0.1325	0.4277	-0.0423	0.0914	0.6385	0.2991	0.1433	0.2201	0.2738	0.4203
	4	0.1645	0.3218	0.2189	0.1616	0.3153	-0.6932	-0.0808	0.2106	0.0598	0.0300	0.0199	0.2020	0.2192
	5	0.5207	0.2205	0.0086	0.1212	0.1052	-0.9852	0.6695	0.1129	-0.0645	0.3257	0.3696	0.3747	0.4698
h^2b	1	0.5979	0.6037	0.2612	0.0394	0.5749	0.6802	0.2210	0.6774	0.6910	0.6304	0.6225	0.6961	0.6131
	2	0.5976	0.2808	0.1881	-1.7819	0.4810	0.1131	0.3716	0.5660	0.6763	0.2401	0.4377	0.4916	0.4379
	3	0.9138	0.6438	0.0832	0.2127	0.4500	0.1606	0.2275	0.6878	0.3660	0.1270	0.2402	0.2762	0.4495
	4	0.3218	0.3747	0.3301	0.1998	0.3214	-0.4107	-0.1143	0.4676	0.1291	0.0814	0.0346	0.2167	0.2244
	5	0.7141	0.2849	-0.0895	0.3220	0.2907	-0.5776	0.7515	-0.0170	-0.0846	0.3097	0.3249	0.3407	0.4206
rsd	1	-0.1395	0.1478	0.1573	0.5865**	-0.4059*	0.4334*	-0.2305	0.0331	-0.1136	0.5600**	0.6523**	0.6991**	0.6900**
	2	0.2286	-0.1152	-0.2280	0.0999	0.0263	-0.2193	0.2776	0.0614	-0.0073	-0.8861**	-0.8693**	-0.8083**	-0.8898**
	3	0.5963**	-0.1051	-0.1723	-0.0202	-0.0805	-0.5338**	-0.0765	0.4346*	0.2556	0.0400	0.2062	-0.0867	0.0495
	4	-0.3837*	-0.1687	0.1935	-0.0908	-0.1463	-0.2931	-0.2238	-0.1807	-0.0968	0.0752	-0.2071	0.1443	-0.2517
	5	0.4011*	-0.1300	0.0871	0.0823	-0.2285	-0.2733	0.4617*	-0.0479	0.2849	-0.3021	0.1338	0.0774	0.1851

* and ** indicate significant at 5% and 1% level, respectively .

Correlation between sums ($\bar{L}_{1i}+\bar{L}_{2i}+\bar{L}_{3i}$) and differences ($\bar{L}_{1i}-\bar{L}_{2i}$) i.e., direction of dominance ($r_{s,d}$) were positive and significant for NSBFF, PHMF, NPd/P, PdW/P, NS/P and SW/P in cross-1; for DFF and NSBMF in cross-3 and for DFF and NPBMF in cross-5 while, negative and significant for DMF in cross-1; for NPd/P, PdW/P, NS/P and SW/P in cross-2; for PHMF in cross-3 and for DFF in cross-4. Positive and significant correlation between sums and differences indicated the direction of dominance towards decreasing parents whereas, negative and significant correlation between sums and differences indicated the direction of dominance towards increasing parents. The direction of dominance of the rest of the traits in different crosses showed non-significant correlation. Non-significant correlation suggested dominant alleles were dispersed between testers; therefore, did not show any proof of directional dominance for these characters (Saleem *et al.* 2009).

Though, the estimation of total epistasis was non-significant for all the traits indicating that there was no significant roles of epistatic effect in the expression of any traits in this study but after partitioning of epistasis, the involvement of ‘i’ type (additive × additive) of epistasis for DFF, PHFF, PWH, NPd/P, PdW/P, NS/P and SW/P in cross-1; for NPBFF and NSBFF in cross-3 and for PHFF, DMF, PHMF and NSBMF in cross-5 was found. It is recognized that the additive × additive (‘i’) type of epistasis can be fixed in the early generation due to its linear directional nature. Therefore, pure lines can be developed through the simple selection procedure of the above characters in the respective crosses. The predominance of additive and dominance type of gene action for yield and some of the important yield traits was also observed in the present work, as both additive and dominance gene effects were significant for most of the characters, simple selection procedures in the immediate progenies will not help in achieving improvement in the characters. Thus, it can be exploited effectively following random intermating in segregating generations and selection in later generations.

Acknowledgements

University Grants Commission and Ministry of Education, Govt. of the People’s Republic of Bangladesh are gratefully acknowledged for providing necessary facilities to carry out the research work.

References

Azad AK 2012. Evaluation of genetic nature and selection index study of yield and yield components in irradiated lines of lentil (*Lens culinaris* Medic). PhD Thesis, University of Rajshahi, Bangladesh. pp. 1-207.

Comstock RE and Robinson HF 1952. Estimation of average dominance of genes. In: *Heterosis*. J.W. Gowen, (Ed.). Iowa State College Press, Ames. pp. 494-516.

Hassan-Sher, Iqbal M, Khan K, Yasir M, Rahman H 2012. Genetic analysis of maturity and flowering characteristics in maize (*Zea mays* L.). Asian Pacific J. Tropic. Biomedicine **2**: 621-626.

Kearsey MJ and Jinks JL 1968. A general method of detecting additive, dominance and epistatic variation for metrical traits. I. Theory. Heredity **23**: 403-409.

Ketata H, Smith EL, Edwards LK and McNew RW 1976. Detection of epistasis, additive and dominance variation in winter wheat. Crop Sci. **16**: 1-4.

Khan AA and McNeilly T 2005. Tiple test cross analysis for salinity tolerance based upon seedling root length in maize (*Zea mays* L.). Breed. Sci. **55**: 321-325.

Khattak GSS, Haq MA, Ashraf M and Tahir GR 2002. Triple test cross analysis for some morphological traits in mungbean (*Vigna radiata* (L.) Wilczek). Euphytica **126**: 413-420.

Kumar N, Sood BC, Sharma TR, Chahota RK and Sood S 2011. Determination of gene action for some biometrical traits in *Lens culinaris*Medic. under mid-hill conditions of northwestern Himalayas. J. Genet. **90**(3): 493-497.

Malhotra RS and Singh KB 1989. Detection of epistasis in chickpea. Euphytica **40**:169-172.

Pavan R, Gangappa E, Ramesh S, Rao AM and Shailaja H 2017. Detection of epistasis through triple test cross (TTC) analysis in maize (*Zea mays* L.). J. Appl. Nat. Sci**. 9**(4): 2496-2501.

Ram T, Deen R, Mishra B, Padmavathi G, Prasad ASR and Viraktamath BC 2007. Triple test cross analysis for yield and yield components in rice (*Oryza sativa* L.). Indian Agric. Sci. **77**(6): 393-395.

Saleem MY, Mirza JI and Haq MA 2009. Triple test cross analysis of some physio-morphological traits in Basmati rice (*Oryza sativa* L.). Pakistan J. Bot. **45**(5): 2411-2418.

Saravanan K, Sabesan T, Kumar NS and Ganssan J 2005. Triple test cross analysis in bhendi (*Abelmoschus esculentus* L. Moench). Indian J. Agric. Res. **39**(4): 242-248.

Verma RS, Yadav RDS and Giri SP 2006. Genetics of yield and its important components in rice (*Oryzasativa* L.). Crop Res. (Hisar) **31**(1): 142-146.

Wood JA and Grusak MA 2007. Nutritional value of chickpea. *In*: Chickpea Breeding and Management, Yadav SS, Redden B, Chen W and Sharma B (Eds), pp. 101-142. CAB International, Wallingford, Oxfordshire, OX10 8DE, UK.

Yadav SS, Redden B, Chen W and Sharma B 2007. Chickpea Breeding and Management. CAB International, Wallingford, Oxfordshire, OX10 8DE, UK. pp. xvii.

Zafar M, Khan AS, Chowdhry MA and Bhatti MA 2008. Triple test cross analysis for salinity tolerance in wheat. Pakistan J. Agri. Sci. **45**(3): 40-43.

(Manuscript received on 25 January, 2020; revised on 31 August, 2020)