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Gene Effects for Yield and Yield Components in Chickpea (*Cicer arietinum* L.) under Irrigated and Rainfed Conditions

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Abstract

Seven genetically diverse parents of chickpea were crossed in five combinations (RSG-895 x RSG-888, RSG-888 x ICC-4958, IPC-94-94 x RSG-888, CSJD-901 x RSG-931 and BG-362 x RSG-931) to develop F_1, F_2 and F_3 hybrid progenies. Five generations *viz.,* P_1, P_2, F_1, F_2 and F_3 were grown in a compact family block design under irrigated and rainfed conditions to estimate the gene effects for yield and yield components. Scaling test 'C' and 'D' as well as joint scaling test revealed presence of epistatic in all the crosses for all the characters studied *viz.,* days to 50% flowering, days to maturity, plant height, fruiting branches per plant, pods per plant, seeds per pod, biological yield per plant, seed yield per plant, harvest index, 100-seed weight and protein content under both the conditions. Both main effects additive (d) and dominance (h) were important for all the characters in all the crosses under both the conditions except 100-seed weight, where only additive effect was found important. Both additive x additive (i) and dominance x dominance (l) interaction effects were also important for all the characters in all the crosses under both the conditions except 100-seed weight, where only additive x additive interaction was found important. Generally, the magnitudes of dominance (h) and dominance x dominance (l) were prevailed over additive (d) and additive x additive (i) effects, respectively. Duplicate type of epistasis was observed in all the cases, where epistasis was established. Thus, it can be concluded that additive, dominance, additive x additive (i) and dominance x dominance (l) effects contributed significantly to the inheritance of various component characters in chickpea under both irrigated and rainfed conditions. These results implies the use of recurrent selection by way of intermating the desirable segregants followed by selection or biparental approach/intermating of segregants in early segregating generations for improvement of these components characters in chickpea under both the conditions.

Keywords: chickpea, gene effects, epistasis, inheritance, *Cicer arietinum*

1. Introduction

Chickpea (*Cicer arietinum* L.) is the third most important pulse crop (after dry bean and pea) and currently grown on about 10 mha world wide, with 95% cultivation in the developing countries. In Asia, India accounts for 65.3% of the area and 67.2% of the production. Chickpea has special significance in the diet of the predominantly vegetarian population of India as it contains more protein, which is complementary with cereals in amino acids profile. However, production and productivity of chickpea have been stagnant for the past three decades. One of the main reason is its sensitive to moisture stress at critical stages as more than 80% area under chickpea is rainfed.

The precise knowledge of the nature of gene action for yield attributing traits helps in the choice of an effective breeding strategy to accelerate the pace of genetic improvement of seed yield. Most of the reports for gene action in chickpea are based on the diallel mating (Katiyar & Singh, 1980, Deshmukh & Bhapkar, 1982) which does not provide information regarding non-allelic gene actions. The non-allelic gene actions could inflate the measures of additive and dominance components. Further, Toledo et al. (1991) suggested that the five-parameter model was good as the back cross studies for estimation of gene effects and gives satisfactory results.

Keeping this in mind, the present investigation was carried out to determine the gene effects for yield and yield components in five crosses of chickpea under irrigated and rainfed conditions through generation mean analysis.

2. Materials and Methods

2.1 Plant Material

Seven *desi* chickpea cultivars *viz.,* RSG-895, RSG-888, ICC-4958, IPC-94-94, CSJD-901, RSG-931 and BG-362 of diverse pedigree, seed size origin and agro-climatic adaptation were crossed in five combinations *viz.,* RSG-895 x RSG-888, RSG-888 x ICC-4958, IPC-94-94 x RSG-888, CSJD-901 x RSG-931 and BG-362 x RSG-931. Five generations *viz.,* P_1, P_2, F_1, F_2 and F_3 of these five crosses were grown in a compact family block design with three replications during *rabi* 2004-05 under both irrigated (two supplemental irrigations) and rainfed (on receding soil moisture i.e. conserved moisture from rainfall prior sowing which was 122.6 mm) at Research Farm, Agricultural Research Sub Station, Hanumangarh. Seeds were sown in 3 meter long rows. Keeping spacing between and within rows at 0.30 m x 0.10 m. Parents were represented by two rows, F_1s by one row, F_2s and F_3s by four rows. Observations for eleven yield related characters *viz.,* days to 50% flowering, days to maturity, plant height, fruiting branches per plant, pods per plant, seeds per pod, biological yield per plant, seed yield per plant, harvest index, 100-seed weight and protein content were recorded on 10 randomly selected plants in P_1, P_2 and F_1 generations and on 20 plants in F_2 and F_3 generations.

2.2 Statistical Analysis

ANOVA was performed as per compact family block design for comparison of crosses as well as generations of each cross. Pooled analysis of variance was also done over two environments (Irrigated and rainfed) according to Panse and Sukhatme (1985). The scale tests ‘C’ and ‘D’ (Mather, 1949) were applied to test the presence or absence of non-allelic interaction. Joint Scaling (Cavalli, 1952) was applied to find out the presence of interaction and estimate the m, (d) and (h) parameters. Significant χ^2- values of joint scaling test suggested the inadequacy of additive-dominance model and it was considered appropriate to use five-parameter model of Hayman (1958) for the estimation of gene effects under both the conditions.

3. Results and Discussion

The mean squares from ANOVA presented in Table 1 showed that there were significant differences among crosses as well as in generations. The pooled analysis of variance over environments (irrigated and rainfed) presented in Table 2, revealed highly significant differences between environments for all the characters in all the crosses except for seeds per pod in cross RSG-888 x ICC-4958 and BG-362 x RSG-931. Significant differences between the environments, indicating the effect of environments on expression of characters. Generation x Environment interaction also significant for most of the characters in all the crosses except for seeds per pod in RSG-895 x RSG-888, RSG-888 x ICC-4958 and BG-362 x RSG-931, for 100-seed weight in RSG-888 x ICC-4958, IPC-94-94 x RSG-888 and BG-362 x RSG-931 and protein content in RSG-895 x RSG-888 and RSG-888 x ICC-4958, which indicated the variable effect of environments on the expression of characters. The scaling tests ‘C’ and ‘D’ and Joint Scaling test (χ^2- values) indicated the presence of epistatic interactions in all the crosses for all the characters under both the conditions (Table 3). The genetic architecture of individual characters is discussed below.

3.1 Days to 50% Flowering

Both additive (d) and dominance (h) effects were significant in all the crosses under both the conditions except for dominance in IPC-94-94 x RSG-888 under rainfed, with a greater magnitude of dominance than additive, indicating predominance of dominance for days to 50% flowering. Similarly, both additive x additive (i) and dominance x dominance (l) interactions were significant in all the crosses under both the conditions except for additive x additive in RSG-895 x RSG-888 and CSJD-901 x RSG-931 and dominance x dominance in IPC-94-94 x RSG-888 in irrigated condition. Higher magnitude of dominance x dominance than additive x additive indicated the importance of dominance x dominance (l) for inheritance of this trait.

Table 1. Analysis of variance (mean squares) for different characters in five generations and five crosses of chickpea under irrigated (IRG) and rainfed (RF) conditions as per compact family block design

Between crosses:

Characters	IRG			RF		
	Rep. (2 df)	Crosses (4 df)	Error (8 df)	Rep. (2 df)	Crosses (4 df)	Error (8 df)
Days to 50% flowering	0.070	51.708**	0.096	0.037	198.05**	0.081
Days to maturity	0.174	88.793**	0.316	0.167	147.186**	0.033
Plant height (cm)	0.058	55.084**	0.449	0.148	19.633**	0.231
Fruiting branches per plant	0.258	1.455**	0.172	0.043	6.927**	0.106
Pods per plant	0.578	24.465**	1.405	1.281	52.503**	0.499
Seeds per pod	0.002	0.045**	0.001	0.003	0.019**	0.001
Biological yield per plant(g)	0.365	19.267**	0.318	0.478	22.987**	0.271
Seed yield per plant (g)	0.131	7.788**	0.130	0.089	18.029**	0.219
Harvest index (%)	0.248	7.848**	0.603	0.251	51.117**	0.205
100-seed weight (g)	0.098	35.574**	0.086	0.030	29.679**	0.165
Protein content (%)	0.016	0.622**	0.023	0.005	0.689**	0.008

Between generations within crosses:

Characters	IRG			RF		
	Rep. (2 df)	Gener. (4 df)	Error (8 df)	Rep. (2 df)	Gener. (4 df)	Error (8 df)
Days to 50% flowering						
RSG-895 x RSG-888	1.445	18.681**	2.090	0.002	7.390**	0.916
RSG-888 x ICC-4958	0.048	12.398**	1.176	0.269	12.164**	1.016
IPC-94-94 x RSG-888	0.064	319.744**	3.233	0.868	242.273**	3.534
CSJD-901 x RSG-931	0.452	4.144*	0.850	0.200	7.599**	0.783
BG-362 x RSG-931	0.266	8.126**	0.850	0.464	22.468**	0.633
Days to maturity						
RSG-895 x RSG-888	1.364	11.592*	1.947	0.171	16.669**	0.640
RSG-888 x ICC-4958	2.561	24.823**	0.779	0.061	17.013**	0.907
IPC-94-94 x RSG-888	2.399	250.044**	13.900	0.198	277.193**	3.117
CSJD-901 x RSG-931	0.598	12.766**	0.766	0.468	15.235**	0.968
BG-362 x RSG-931	0.268	33.388**	1.682	0.599	18.073**	1.684
Plant height (cm)						
RSG-895 x	0.001	40.021**	1.637	0.242	13.272*	2.379

RSG-888						
RSG-888 x ICC-4958	1.081	37.791**	4.305	2.539	15.087**	2.051
IPC-94-94 x RSG-888	0.839	54.150**	5.200	1.032	53.350**	3.422
CSJD-901 x RSG-931	5.069	40.133**	3.348	0.945	18.129**	1.731
BG-362 x RSG-931	2.281	28.138**	3.591	0.611	55.511**	6.429
Fruiting branches per plant						
RSG-895 x RSG-888	0.132	16.421**	0.788	0.997	7.565**	0.765
RSG-888 x ICC-4958	1.391	18.542**	1.623	0.572	6.489**	0.524
IPC-94-94 x RSG-888	0.640	25.117**	1.067	0.500	12.694**	0.915
CSJD-901 x RSG-931	2.464	20.678**	0.730	0.162	5.592**	0.745
BG-362 x RSG-931	0.098	17.179**	0.628	0.098	6.805**	0.254
Pods per plant						
RSG-895 x RSG-888	13.089	331.556**	16.37	1.237	173.984**	3.208
RSG-888 x ICC-4958	1.798	142.749**	12.227	4.862	263.506**	3.416
IPC-94-94 x RSG-888	3.174	151.826**	9.067	1.335	152.074**	6.353
CSJD-901 x RSG-931	9.204	115.315**	14.863	7.074	177.750**	6.860
BG-362 x RSG-931	3.725	127.541**	10.562	1.866	147.495**	7.105
Seeds per pod						
RSG-895 x RSG-888	0.016	0.041*	0.008	0.006	0.034**	0.004
RSG-888 x ICC-4958	0.002	0.078**	0.011	0.007	0.076**	0.004
IPC-94-94 x RSG-888	0.003	0.043*	0.008	0.003	0.045**	0.001
CSJD-901 x RSG-931	0.011	0.064**	0.009	0.001	0.019**	0.001
BG-362 x RSG-931	0.003	0.024**	0.003	0.003	0.039**	0.003
Biological yield per plant (g)						
RSG-895 x RSG-888	2.423	45.621**	2.995	1.991	31.965**	2.133
RSG-888 x ICC-4958	0.992	68.477**	2.640	0.879	81.273**	1.912
IPC-94-94 x RSG-888	0.084	50.796**	2.072	1.487	33.537**	2.784

CSJD-901 x RSG-931	3.787	28.793*	4.187	0.917	30.259**	1.191
BG-362 x RSG-931	0.904	76.659**	4.451	2.529	38.431**	2.148
Seed yield per plant (g)						
RSG-895 x RSG-888	0.588	20.359**	1.200	1.666	15.436**	0.738
RSG-888 x ICC-4958	0.117	27.273**	1.123	1.336	41.168**	0.885
IPC-94-94 x RSG-888	0.722	12.402**	1.194	0.578	19.553**	0.762
CSJD-901 x RSG-931	1.274	10.832**	0.867	0.989	6.320**	0.345
BG-362 x RSG-931	0.566	25.112**	1.242	0.259	30.401**	1.415
Harvest index (%)						
RSG-895 x RSG-888	10.479	67.467**	5.798	1.283	66.859**	3.276
RSG-888 x ICC-4958	1.297	77.514**	1.359	1.807	71.264**	1.842
IPC-94-94 x RSG-888	0.629	28.351**	1.514	0.591	62.157**	1.106
CSJD-901 x RSG-931	0.200	16.665*	2.504	0.258	13.102**	1.384
BG-362 x RSG-931	0.682	37.732**	1.614	1.428	91.035**	1.379
100-seed weight (g)						
RSG-895 x RSG-888	0.061	2.157**	0.094	0.326	1.972**	0.060
RSG-888 x ICC-4958	1.256	75.130**	4.095	0.083	57.462**	0.503
IPC-94-94 x RSG-888	0.310	39.523**	2.176	1.515	28.635**	1.011
CSJD-901 x RSG-931	0.127	2.588**	0.144	0.163	3.884*	0.643
BG-362 x RSG-931	0.461	44.749**	0.939	1.362	34.737**	0.654
Protein content (%)						
RSG-895 x RSG-888	0.183	1.145*	0.202	0.064	0.946**	0.066
RSG-888 x ICC-4958	0.055	1.929**	0.049	0.018	1.258**	0.041
IPC-94-94 x RSG-888	0.059	4.952**	0.094	0.055	3.812**	0.061
CSJD-901 x RSG-931	0.193	2.515**	0.192	0.033	0.917**	0.027
BG-362 x RSG-931	0.052	1.659**	0.191	0.019	0.132**	0.017

*, ** significant at 5 per cent and 1 per cent level, respectively

Table 2. Pooled analysis of variance (mean squares) in five chickpea crosses over two environments (irrigated and rainfed)

Characters/crosses	Env.(E) (1df)	Rep./ Env. (4 df)	Gener.(G) (4 df)	G x E (4 df)	Error (16 df)
Days to 50% flowering					
RSG-895 x RSG-888	412.799**	0.722	9.586**	16.483**	1.504
RSG-888 x ICC-4958	208.086**	0.159	20.624**	3.938*	1.096
IPC-94-94 x RSG-888	1320.254**	0.466	428.814**	133.202**	3.384
CSJD-901 x RSG-931	265.083**	0.326	7.858**	3.885*	0.816
BG-362 x RSG-931	40.756**	0.366	26.680**	3.913**	0.741
Days to maturity					
RSG-895 x RSG-888	418.133**	0.766	20.391**	7.868**	1.294
RSG-888 x ICC-4958	172.400**	1.312	30.251**	11.586**	0.843
IPC-94-94 x RSG-888	580.800**	1.300	494.347**	32.892*	8.508
CSJD-901 x RSG-931	224.079**	0.533	22.371**	5.630**	0.867
BG-362 x RSG-931	73.299**	0.434	32.991**	18.471**	1.683
Plant height (cm)					
RSG-895 x RSG-888	337.234**	0.121	41.525**	11.768**	2.008
RSG-888 x ICC-4958	250.377**	1.812	24.789**	28.089**	3.178
IPC-94-94 x RSG-888	43.056**	0.936	86.982**	20.519*	4.311
CSJD-901 x RSG-931	121.874**	3.006	36.605**	21.657**	2.540
BG-362 x RSG-931	318.220**	1.446	59.894**	23.755*	5.010
Fruiting branches per plant					
RSG-895 x RSG-888	137.217**	0.565	17.083**	6.903**	0.776
RSG-888 x ICC-4958	27.950**	0.983	18.536**	6.496**	1.073
IPC-94-94 x RSG-888	24.300**	0.570	24.441**	13.369**	0.991
CSJD-901 x RSG-931	19.976**	1.311	22.873**	3.395*	0.738
BG-362 x RSG-931	11.371**	0.099	19.045**	4.941**	0.441
Pods per plant					
RSG-895 x RSG-888	973.674**	7.163	419.413**	86.127**	9.789
RSG-888 x ICC-4958	650.164**	3.330	341.484**	64.771**	7.821
IPC-94-94 x RSG-888	635.904**	2.256	251.215**	52.686**	7.710
CSJD-901 x RSG-931	1152.828**	8.139	224.393**	68.672**	10.861
BG-362 x RSG-931	555.212**	2.795	231.613**	43.422**	8.834
Seeds per pod					
RSG-895 x RSG-888	0.033*	0.011	0.071**	0.004	0.006
RSG-888 x ICC-4958	0.033	0.004	0.150**	0.003	0.007
IPC-94-94 x RSG-888	0.039*	0.001	0.069**	0.016*	0.005
CSJD-901 x RSG-931	0.035*	0.006	0.066**	0.015*	0.005
BG-362 x RSG-931	0.017	0.001	0.057**	0.004	0.004
Biological yield per plant (g)					
RSG-895 x RSG-888	191.572**	2.206	60.081**	17.504**	2.564

RSG-888 x ICC-4958	385.137**	0.936	111.629**	38.121**	2.276
IPC-94-94 x RSG-888	140.078**	0.787	54.584**	29.749**	2.428
CSJD-901 x RSG-931	358.111**	2.351	30.553**	28.498**	2.689
BG-362 x RSG-931	68.675**	1.716	90.519**	24.570**	3.30
Seed yield per plant (g)					
RSG-895 x RSG-888	172.777**	1.125	25.269**	10.524**	0.970
RSG-888 x ICC-4958	23.870**	0.726	62.193**	6.248**	1.004
IPC-94-94 x RSG-888	9.509**	0.650	16.413**	15.542**	0.978
CSJD-901 x RSG-931	62.400**	1.132	14.272**	2.879*	0.606
BG-362 x RSG-931	19.018**	0.414	51.234**	4.280*	1.328
Harvest index (%)					
RSG-895 x RSG-888	231.778**	5.879	96.939**	37.386**	4.537
RSG-888 x ICC-4958	29.489**	1.553	123.058**	25.721**	1.600
IPC-94-94 x RSG-888	132.806**	0.609	48.440**	42.067**	1.310
CSJD-901 x RSG-931	30.724**	0.229	16.441**	13.326**	1.944
BG-362 x RSG-931	17.328**	1.054	107.491**	21.276**	1.497
100-seed weight (g)					
RSG-895 x RSG-888	1.152**	0.191	3.784**	0.344*	0.077
RSG-888 x ICC-4958	14.658*	0.669	131.818**	0.774	2.299
IPC-94-94 x RSG-888	8.175*	0.912	67.174**	0.984	1.593
CSJD-901 x RSG-931	4.074**	0.144	4.718**	1.753*	0.394
BG-362 x RSG-931	3.931*	0.913	78.924**	0.563	0.796
Protein content (%)					
RSG-895 x RSG-888	1.298**	0.125	1.947**	0.145	0.134
RSG-888 x ICC-4958	0.252*	0.035	3.075**	0.111	0.045
IPC-94-94 x RSG-888	0.666**	0.057	8.523**	0.241*	0.078
CSJD-901 x RSG-931	1.285**	0.113	2.610**	0.823**	0.109
BG-362 x RSG-931	2.191**	0.037	1.288**	0.505**	0.104

*, ** significant at 5 per cent and 1 per cent level, respectively

3.2 Days to Maturity

Main effects *i.e.,* additive (d) and dominance (h) were significant in all the crosses under both the conditions. Among the two, the magnitudes of dominance effect prevailed over their respective additive gene effects in all the crosses except RSG-888 x ICC-4958 in irrigated and IPC-94-94 x RSG-888 in both irrigated and rainfed conditions, indicating importance of dominance effect in the inheritance of this trait. Among the digenic interactions, additive x additive (i) and dominance x dominance (l) interactions were significant in all the crosses under both the conditions except additive x additive in RSG-895 x RSG-888 and dominance x dominance in IPC-94-94 x RSG-888 under rainfed. Higher magnitude of dominance x dominance (l) than additive x additive (i) interaction in all the crosses except IPC-94-94 x RSG-888 under both the conditions- indicated its importance in the inheritance of this trait.

Table 3. Estimates of scaling test and gene effects for different characters in five chickpea crosses under irrigated (IRG) and rainfed (RF) conditions

Characters/crosses	Env.	Scaling test		$\chi 2_{(2)}$	m	(d)	(h)	(i)	(l)	Epistasis
		C	D							
Days to 50% flowering										
RSG-895 x RSG-888	IRG	2.66*±1.16	-6.40**±1.44	22.01**	93.00±0.23	-1.67**±0.19	9.38**±1.01	1.38±0.92	-12.09**±2.67	D
	RF	-2.94**±0.68	0.65±0.56	19.32**	83.17±0.11	-1.50**±0.12	-3.45**±0.41	-3.92**±0.44	4.79**±1.24	D
RSG-888 x ICC-4958	IRG	0.00±0.69	-6.00**±0.85	51.71**	94.00±0.14	-2.67**±0.13	4.67**±0.58	-1.33*±0.56	-8.00**±1.57	D
	RF	-5.00**±0.76	5.66**±0.72	87.84**	87.00±0.14	-2.50**±0.11	-5.77**±0.52	-9.61**±0.52	14.21**±1.53	D
IPC-94-94 x RSG-888	IRG	20.01**±1.34	21.32**±0.98	1072.27**	87.67±0.30	-12.67**±0.24	-2.21**±0.73	-36.21**±0.90	1.75±2.56	-
	RF	-24.35**±1.17	-14.99**±1.14	842.24**	66.33±0.26	-11.17**±0.20	0.44±0.82	-16.40**±0.88	12.48**±2.48	-
CSJD-901 x RSG-931	IRG	2.28**±0.72	-1.79**±0.58	17.45**	91.90±0.12	-1.00**±0.14	3.57**±0.42	-0.43±0.48	-5.43**±1.30	D
	RF	3.00**±0.68	-7.33**±0.57	176.82**	85.83±0.11	-1.83**±0.13	3.88**±0.40	1.72**±0.46	-13.78**±1.24	D
BG-362 x RSG-931	IRG	3.67**±0.74	-4.99**±0.73	57.52**	95.33±0.16	2.17**±0.11	3.77**±0.53	8.28**±0.53	-11.54**±1.55	D
	RF	7.35**±0.66	2.01**±0.57	144.48**	93.67±0.11	3.34**±0.13	2.22**±0.40	6.55**±0.45	-7.12**±1.22	D
Days to maturity										
RSG-895 x RSG-888	IRG	4.02**±1.86	-6.65**±1.33	25.35**	138.67±0.43	1.33**±0.23	8.44**±1.06	7.77**±1.22	-14.22**±3.70	D
	RF	0.34±1.14	-6.34**±1.13	31.91**	130.67±0.23	-1.83**±0.20	8.45**±0.81	0.62±0.82	-8.91**±2.34	D
RSG-888 x ICC-4958	IRG	1.00±1.16	-7.67**±1.12	47.22**	138.00±0.22	-3.83**±0.23	3.78**±0.78	-2.38**±0.83	-11.56**±0.29	D
	RF	2.12±1.14	-2.72*±1.09	8.14*	134.03±0.23	-2.00**±0.20	6.51**±0.78	-1.83*±0.81	-6.45**±2.31	D
IPC-94-94 x RSG-888	IRG	7.66**±2.37	16.34**±1.98	101.67**	125.00±0.50	-12.50**±0.41	-7.79**±1.45	-34.61**±1.67	11.57*±4.66	D
	RF	-10.99**±1.46	-15.01**±1.34	240.08**	114.00±0.29	-13.17**±0.20	6.68**±0.99	-18.17**±1.00	-5.35±2.95	-
CSJD-901 x RSG-931	IRG	5.01**±1.08	-0.34±1.10	21.46**	134.67±0.20	1.50**±0.22	4.89**±0.76	4.06**±0.79	-7.12**±2.17	D
	RF	2.99**±1.11	-0.35±1.08	7.24**	129.00±0.20	-1.17**±0.21	5.57**±0.76	-1.60*±0.78	-4.45*±2.18	D
BG-362 x RSG-931	IRG	-0.96±1.17	4.38**±1.30	11.56**	134.00±0.22	4.52**±0.22	-4.90**±0.90	5.95**±0.87	7.12**±2.47	D
	RF	3.64**±1.18	10.32**±1.13	101.76**	132.33±0.23	1.50**±0.25	-1.77*±0.78	-3.27**±0.82	8.91**±2.30	D
Plant height (cm)										
RSG-895 x RSG-888	IRG	7.90±4.58	-14.64**±4.65	10.92**	61.00±0.98	2.05**±0.79	17.29**±3.31	15.18**±3.37	-30.05**±9.69	D
	RF	0.40±3.47	-10.04**±2.77	13.77**	52.33±0.66	-1.20±0.53	10.16**±2.08	4.36±2.26	-13.92*±6.61	D
RSG-888 x ICC-4958	IRG	6.92±4.11	11.02**±4.06	11.13**	59.23±0.73	-4.47**±0.84	-6.39*±2.81	-15.13**±2.82	5.47±8.04	-
	RF	0.47±3.34	13.49**±2.93	23.76**	52.82±0.71	1.13*±0.52	-4.98*±2.16	-6.64**±2.29	17.36*±6.74	D
IPC-94-94 x RSG-888	IRG	7.51±4.08	10.47**±3.57	15.55**	50.23±0.84	-5.57**±0.72	-5.69*±2.58	-16.86**±2.84	3.95±8.05	-
	RF	-1.54±3.59	-15.04**±2.68	38.32**	48.05±0.76	-4.90**±0.54	13.30**±2.06	-0.03±2.35	-18.00**±6.92	D
CSJD-901 x RSG-931	IRG	4.73±4.34	-12.25**±3.53	12.22**	56.45±0.96	-2.60**±0.46	15.22**±2.75	3.75±2.91	-22.64*±8.89	D
	RF	4.48±3.11	11.83**±2.88	18.46**	50.92±0.51	0.93±0.80	-2.54±1.86	-5.28*±2.37	9.80±5.52	-
BG-362 x RSG-931	IRG	2.98±3.81	16.38**±3.63	23.45**	60.45±0.76	2.05**±0.67	-5.44*±2.60	-6.32*±2.69	17.87*±7.71	D
	RF	4.38±3.48	-11.36**±3.25	12.34**	55.18±0.71	5.57**±0.54	10.67**±2.37	19.44**±2.41	-20.99**±7.10	D
Fruiting branches per plant										
RSG-895 x RSG-888	IRG	6.42**±2.38	-3.92±2.60	8.37*	17.68±0.47	-1.25**±0.41	8.19**±1.84	1.18±1.79	-13.79**±5.10	D
	RF	0.63±1.81	8.33**±2.14	16.01**	11.28±0.38	-1.72**±0.37	-4.23**±1.47	-8.88**±1.46	10.27*±4.00	D

RSG-888 x ICC-4958	IRG	3.42±2.34	13.38**±2.72	27.63**	16.67±0.44	1.53**±0.52	-4.32*±1.84	-5.29**±1.89	13.28**±4.96	D
	RF	-0.14±2.37	10.07**±2.00	25.91**	13.97±0.45	-1.00*±0.48	-4.80**±1.40	-8.73**±1.58	13.62**±4.43	D
IPC-94-94 x RSG-888	IRG	2.26±2.89	-11.88**±2.33	26.54**	16.78±0.57	-2.07**±0.42	12.93**±1.76	4.16*±1.90	-18.85**±5.59	D
	RF	3.10±2.51	12.32**±2.17	35.54**	13.62±0.42	-1.45**±0.46	-5.05**±1.55	-10.60**±1.71	12.29**±4.65	D
CSJD-901 x RSG-931	IRG	0.32±2.95	-8.19**±2.80	8.76*	16.43±0.60	-1.97**±0.58	10.08**±1.97	1.58±2.09	-11.35±5.92	-
	RF	5.32*±2.41	-4.46*±2.05	7.28*	15.13±0.51	-0.77*±0.36	6.06**±1.53	2.32±1.63	-13.04**±4.84	D
BG-362 x RSG-931	IRG	3.35±2.97	13.68**±2.58	35.43**	17.32±0.63	-1.20*±0.50	-4.60*±1.88	-10.96**±2.06	13.78*±5.92	D
	RF	-0.39±3.14	9.87**±2.55	16.34**	15.37±0.68	0.97±0.53	-4.38*±1.88	-4.71*±2.20	13.68*±6.17	D
Pods per plant										
RSG-895 x RSG-888	IRG	20.76±10.69	-45.60**±11.82	16.02**	62.75±2.30	-7.15**±1.79	50.08**±8.37	19.56*±8.23	-88.48**±23.60	D
	RF	34.12**±7.43	8.60±8.64	26.99**	50.63±1.67	-2.30*±0.95	13.81*±6.21	-4.65±5.81	-34.03*±17.24	D
RSG-888 x ICC-4958	IRG	11.76±7.09	41.66**±8.32	34.21**	63.28±1.52	3.68**±0.93	-15.63**±5.95	-18.45**±5.49	39.87*±16.29	D
	RF	21.71**±9.07	52.39**±8.98	55.66**	55.72±2.02	-4.99**±1.12	-17.49**±6.64	-41.28**±6.58	40.91*±19.71	D
IPC-94-94 x RSG-888	IRG	8.95±8.26	37.11**±7.23	37.50**	60.17±1.86	-4.97**±1.07	-12.05**±5.46	-33.18**±5.69	37.55*±17.23	D
	RF	5.74±6.93	33.74**±6.99	29.38**	51.00±1.53	3.20**±0.94	-7.47±5.11	-15.14**±5.01	37.33*±15.04	-
CSJD-901 x RSG-931	IRG	4.35±8.92	-27.15**±8.84	9.78**	61.37±1.98	-2.53*±1.07	30.06**±6.54	13.76*±6.44	-42.00*±19.38	D
	RF	52.08**±9.40	-0.46±7.94	35.80**	55.67±2.09	-3.17*±1.24	18.09**±6.03	2.65±6.39	-70.05**±19.29	D
BG-362 x RSG-931	IRG	7.99±8.96	38.71**±8.14	31.70**	61.58±2.00	-3.47**±0.89	-14.04*±6.20	-31.40**±6.18	40.96*±19.05	D
	RF	1.21±13.96	45.51**±10.15	27.28**	51.52±3.23	4.04*±1.80	-19.23*±8.06	-22.07*±9.16	59.07*±27.95	D
Seeds per pod										
RSG-895 x RSG-888	Pooled	-0.02±0.20	-0.86**±0.22	15.66**	1.72±0.04	0.07±0.04	0.58**±0.15	0.71**±0.15	-1.12**±0.41	D
RSG-888 x ICC-4958	Pooled	0.01±0.24	-0.74**±0.21	14.24**	1.51±0.05	0.19**±0.04	0.51**±0.15	0.88**±0.16	-1.00*±0.48	D
IPC-94-94 x RSG-888	IRG	-0.10±0.41	0.94*±0.38	6.21*	1.67±0.09	-0.05±0.07	-0.49±0.28	-0.74*±0.29	1.39±0.85	-
	RF	0.28±0.30	0.60*±0.30	6.06*	1.65±0.07	-0.12*±0.05	-0.41±0.22	-0.59**±0.22	0.43±0.64	-
CSJD-901 x RSG-931	IRG	0.10±0.32	-0.86**±0.33	6.86**	1.79±0.07	0.15**±0.05	0.48*±0.24	0.89**±0.23	-1.28±0.68	-
	RF	0.06±0.26	-0.70*±0.28	6.28*	1.72±0.05	0.03±0.06	0.48*±0.19	0.52*±0.21	-1.01±0.54	-
BG-362 x RSG-931	Pooled	-0.09±0.22	-0.70**±0.19	14.10**	1.66±0.04	0.07±0.04	0.35*±0.14	0.58**±0.15	-0.80±0.42	-
Biological yield per plant (g)										
RSG-895 x RSG-888	IRG	2.96±5.47	-18.80**±5.90	10.19**	41.11±1.11	-2.41**±0.86	19.11**±4.21	8.21*±4.11	-29.01*±11.83	D
	RF	2.94±5.11	-14.62**±5.55	6.95*	35.68±1.02	2.32**±0.80	15.23**±3.95	14.88**±3.78	-23.41*±11.03	D
RSG-888 x ICC-4958	IRG	7.76±5.94	-18.16**±6.68	8.27*	48.32±1.09	-2.79**±1.01	21.76**±4.69	7.82±4.47	-34.56**±12.71	D
	RF	9.19±5.11	26.75**±4.81	37.22**	39.29±0.92	-2.31*±0.97	-7.07*±3.39	-20.91**±3.45	23.41*±9.91	D
IPC-94-94 x RSG-888	IRG	8.97±4.71	-15.40**±4.74	12.30**	43.27±0.92	-2.05*±0.81	19.12**±3.37	7.67*±3.36	-32.49**±9.71	D
	RF	0.61±4.47	15.27**±3.41	20.83**	35.82±0.71	2.02**±0.62	-3.59±2.60	-6.05*±2.67	19.55*±8.06	-
CSJD-901 x RSG-931	IRG	-5.11±5.75	16.39**±4.89	11.35**	38.11±1.25	-1.88*±0.81	-5.79±3.68	-15.55**±4.00	28.67*±11.67	-
	RF	13.46±4.81	-20.96**±3.84	31.50**	35.52±0.95	-2.73**±0.69	16.89**±2.91	10.76**±3.09	-45.89**±9.28	D
BG-362 x RSG-931	IRG	17.69**±5.97	27.89**±5.88	41.49**	44.46±1.25	-2.19*±0.90	-9.20*±4.27	-20.01**±4.27	13.60±12.55	-
	RF	-0.49±7.39	23.37**±5.09	25.21**	38.27±1.59	2.49*±1.05	-10.61**±4.03	-10.69*±4.73	31.81*±14.11	D
Seed yield per plant (g)										
RSG-895 x	IRG	2.91±2.97	13.13**±3.26	21.11**	18.63±0.66	-1.64**±0.42	-3.79±2.35	-11.56**±2.27	13.63*±6.66	-

RSG-888										
	RF	1.10±2.53	-9.88**±2.68	13.63**	14.60±0.48	-1.05*±0.49	10.82**±1.86	4.67*±1.88	-14.64**±5.21	D
RSG-888 x ICC-4958	IRG	4.61±3.08	14.83**±3.17	29.35**	20.73±0.67	1.14*±0.53	-3.39±2.26	-6.85**±2.35	13.63*±6.59	-
	RF	6.44±3.30	19.04**±3.13	41.17**	19.19±0.57	-1.60*±0.77	-5.00*±2.09	-14.82**±2.51	16.80**±6.12	D
IPC-94-94 x RSG-888	IRG	2.43±2.34	-7.65**±2.56	9.37**	19.08±0.47	-1.28**±0.49	9.04**±1.76	2.95±1.78	-13.44**±4.92	D
	RF	0.35±2.74	13.47**±2.21	37.95**	16.63±0.43	1.93**±0.44	-4.75**±1.63	-5.07**±1.68	17.49**±4.97	D
CSJD-901 x RSG-931	IRG	-6.70*±3.22	-4.45±2.96	9.83**	15.09±0.72	-1.11*±0.49	5.32*±2.18	-0.36±2.31	3.00±6.74	-
	RF	5.46*±2.75	-7.36**±2.17	12.55**	14.23±0.55	-0.96*±0.38	7.61**±1.66	3.90*±0.74	-17.09**±5.31	D
BG-362 x RSG-931	IRG	6.20*±2.85	15.73**±2.97	42.01**	20.00±0.61	-0.92*±0.41	-4.46*±2.15	-11.28**±2.09	12.70*±6.18	D
	RF	5.01±3.91	17.21**±2.90	51.77**	18.21±0.86	1.45*±0.56	-5.09*±2.25	-7.75**±2.57	16.27*±7.65	D
Harvest index (%)										
RSG-895 x RSG-888	IRG	4.83±8.00	30.19**±6.74	28.43**	46.45±1.83	-2.82**±0.81	-12.54**±5.23	-24.97**±5.44	33.82*±16.74	D
	RF	5.24±5.78	-13.26**±4.97	7.17*	43.35±1.17	-3.61**±0.90	17.91**±3.67	2.49±3.90	-24.67*±11.43	D
RSG-888 x ICC-4958	IRG	8.66±7.23	30.05**±6.60	31.37**	47.85±1.68	3.17**±0.96	-11.47*±4.94	-12.26*±5.09	28.52±15.40	-
	RF	7.13±5.05	24.05**±4.77	30.47**	50.12±1.02	-2.50*±1.06	-6.04±3.30	-19.84**±3.52	22.56*±9.97	-
IPC-94-94 x RSG-888	IRG	7.47±5.13	-15.05**±5.82	7.23*	47.08±1.11	-1.39*±0.56	16.21**±4.22	8.49*±3.92	-30.03*±11.73	D
	RF	4.15±3.78	23.37**±4.50	27.48**	49.17±0.66	3.18**±1.10	-7.39**±2.84	-8.54**±3.15	25.63**±7.51	D
CSJD-901 x RSG-931	IRG	2.80±3.81	-8.56**±3.26	7.67*	44.24±0.63	-0.90±0.98	10.73**±2.09	4.37±2.66	-15.15**±6.50	D
	RF	-2.52±3.77	12.22**±3.26	14.04**	40.06±0.78	1.61*±0.81	-5.25*±2.26	-5.35*±2.56	19.65**±7.23	D
BG-362 x RSG-931	IRG	3.99±5.02	16.89**±3.95	20.91**	46.02±0.94	-1.65±0.92	-3.78±2.87	-13.89**±3.35	17.21±9.26	-
	RF	11.65**±3.71	25.37**±3.28	78.62**	48.86±0.68	3.03**±0.69	-5.47*±2.34	-8.92**±2.55	18.29**±7.08	D
100-seed weight (g)										
RSG-895 x RSG-888	IRG	0.30±2.23	5.50*±2.35	6.02*	17.00±0.47	0.79*±0.35	-3.07±1.68	-2.04±1.67	6.93±4.82	-
	RF	-0.24±2.42	5.96**±2.17	7.71*	16.60±0.46	0.26±0.44	-2.73±1.55	-3.49*±1.60	8.27±4.67	-
RSG-888 x ICC-4958	Pooled	4.67**±1.67	9.56**±1.83	42.89**	24.70±0.36	-6.09**±0.32	-2.27±1.28	-17.78**±1.27	6.52±3.62	-
IPC-94-94 x RSG-888	Pooled	3.28±1.81	4.90**±1.44	19.61**	22.38±0.36	4.35**±0.28	-0.02±1.08	5.97**±1.19	2.16±3.46	-
CSJD-901 x RSG-931	IRG	1.35±1.66	4.72**±1.43	14.78**	17.14±0.37	0.69*±0.28	-1.52±1.05	-1.54±1.17	4.49±3.36	-
	RF	2.19±1.88	6.39**±2.25	9.10*	16.48±0.27	-0.80±0.45	-2.40±1.50	-5.50**±1.49	5.60±3.81	-
BG-362 x RSG-931	Pooled	7.63**±1.36	7.79**±0.19	79.72**	23.89±0.25	3.78**±0.32	0.95±0.80	3.65**±0.97	0.21±2.48	-
Protein content (%)										
RSG-895 x RSG-888	Pooled	-1.04*±0.51	-1.93**±0.50	21.74**	17.64±0.10	0.71**±0.10	1.08**±0.35	2.53**±0.36	-1.19±1.01	-
RSG-888 x ICC-4958	Pooled	-0.52±0.51	1.30**±0.47	8.01*	18.48±0.10	-0.71*±0.10	0.28±0.33	-2.38**±0.36	2.44*±0.99	-
IPC-94-94 x RSG-888	IRG	-2.25**±0.52	-4.63**±0.49	120.19**	18.25±0.10	1.57**±0.10	2.21**±0.34	5.84**±0.36	-3.17**±1.01	D
	RF	-2.18**±0.53	-1.10*±0.48	25.17**	18.38±0.10	1.50**±0.10	-0.16±0.34	3.37**±0.37	1.44±1.03	-
CSJD-901 x RSG-931	IRG	-1.62*±0.64	0.64±0.51	6.60*	18.19±0.13	1.25**±0.10	-1.01**±0.38	1.80**±0.43	3.01*±1.25	D
	RF	-1.46**±0.51	-1.00*±0.47	15.05**	18.60±0.10	0.32**±0.09	-0.65±0.33	1.06**±0.35	0.61±0.99	-
BG-362 x RSG-931	IRG	-0.88±0.53	-1.94**±0.57	16.24**	18.63±0.10	0.97**±0.10	1.41**±0.40	3.09**±0.40	-1.41±1.11	-
	RF	0.07±0.51	-1.37**±0.47	8.65**	19.25±0.10	0.20*±0.10	0.80*±0.33	1.33**±0.36	-1.92±0.99	-

*, ** significant at 5 per cent and 1 per cent level, respectively

3.3 Plant Height

Main effects, additive (d) and dominance (h) were significant in all the crosses under both the conditions except CSJD-901x RSG-931 under rainfed condition, with greater magnitude of dominance than additive component, indicating predominance of dominance effect for this trait. Both additive x additive (i) and dominance x dominance (l) effects were equally important in the inheritance of this trait. However, the magnitude of dominance x dominance effect prevailed over the additive x additive effect in all the crosses under both the conditions except RSG-888 x ICC-4958 and IPC-94-94 x RSG-888 under irrigated condition, indicating preponderance of dominance x dominance effect in the inheritance of this trait.

3.4 Fruiting Branches per Plant

Both additive (d) and dominance (h) effects were significant in all the crosses under both the conditions except for additive effect in BG-362 x RSG-931 under rainfed condition. The higher magnitude of dominance than additive effect in most of the crosses indicate importance of dominance effect in the inheritance of this trait. Additive x additive (i) and dominance x dominance (l) interactions were also significant in all the crosses under both the conditions except additive x additive (i) in RSG-895 x RSG-888 under irrigated, CSJD-901 x RSG-931 under both the conditions and dominance x dominance (l) in CSJD-901 x RSG-931 under irrigated condition. Higher magnitude of dominance x dominance (l) than additive x additive (i) effect, indicated the importance of dominance x dominance effect.

3.5 Pods per Plant

The main effects, additive (d) and dominance (h) were important in all the crosses except for dominance in IPC-94-94 x RSG-888 under rainfed condition. However, relative magnitude and desirable positive signs revealed the preponderance of dominance (h) over the additive (d) effect, indicating importance of dominance (h) effect for this trait under both the conditions. Among the interaction effects, additive x additive (i) and dominance x dominance (l) interactions were significant for all the crosses under both the conditions except for additive x additive (i) in RSG-895 x RSG-888 and CSJD-901 x RSG-931 under rainfed condition. Higher magnitude of dominance x dominance (l) than additive x additive (i) interaction indicated that dominance x dominance (l) interaction was important for this trait under both the conditions.

3.6 Seeds per Pod

Dominance gene effects were significant for seeds per pod in all the crosses in both the conditions as well as in pooled analysis over environments except IPC-94-94 x RSG-888 under both the conditions and additive effects were significant only in RSG-888 x ICC-4958 under pooled, IPC-94-94 x RSG-888 under rainfed and in CSJD-901 x RSG-931 under irrigated condition, indicating importance of dominance effect in the inheritance of this trait. Among the interaction effects, additive x additive (i) gene effect was significant in all the crosses under both irrigated and rainfed conditions as well as in pooled analysis over environments, whereas dominance x dominance (l) gene action was significant only in two crosses *i.e.,* RSG-895 x RSG-888 and RSG-888 x ICC-4958 under pooled analysis over environments, indicating the importance of additive x additive (i) effect in the inheritance of this trait.

3.7 Biological Yield per Plant

WIth regards to main effects both the main effects *i.e.,* additive (d) and dominance (h) were important for the inheritance of this trait in all the crosses under both the conditions except for dominance in IPC-94-94 x RSG-888 under rainfed and in CSJD-901 x RSG-931 under irrigated condition. However, the magnitude of dominance (h) effect was higher than additive effect-indicating predominance of dominance effect for this trait. Similar, reports were also reported by Bhardwaj and Sandhu (2007) and Gupta et al. (2007). Additive x additive (i) and dominance x dominance (l) effects were also important for the inheritance of this trait in all the crosses under both the conditions except for additive x additive (i) in RSG-888 x ICC-4958 and dominance x dominance (l) in BG-362 x RSG-931 under irrigated condition. The magnitude of dominance x dominance (l) was higher than the additive x additive (i) which- indicated that dominance x dominance interaction played greater role in controlling of this trait.

3.8 Seed Yield per Plant

Both main effects *i.e.*, additive (d) and dominance (h) were significant in all the crosses under both the conditions except for dominance in RSG-895 x RSG-888 and RSG-888 x ICC-4958 under irrigated condition. The magnitudes of dominance (h) were higher than their respective additive effect, indicating predominance of dominance effect for the inheritance of seed yield per plant. Additive x additive (i) and dominance x dominance (l) effects were also significant in all crosses under both the conditions except for additive x additive (i) in

IPC-94-94 x RSG-888 under irrigated and CSJD-901 x RSG-931 under both the conditions with a greater magnitude of dominance x dominance interaction which- indicated the importance of dominance x dominance (l) interaction in controlling the inheritance of this trait.

3.9 Harvest Index

Both the main effects additive (d) and dominance (h) were significant in all the crosses under both the conditions except for dominance (h) in RSG-888 x ICC-4958 under rainfed, additive (d) in CSJD-901 x RSG-931 under irrigated and both additive (d) and dominance (h) in BG-362 x RSG-931 under both the conditions with a greater magnitude of dominance than additive effect- indicating predominance of dominance effect for the inheritance of this trait in both rainfed and irrigated conditions. The digenic interactions (i) and (l) were significant in all the cases except for additive x additive (i) in RSG-895 x RSG-888 under rainfed and CSJD-901 x RSG-931 under irrigated and for dominance x dominance (l) in RSG-888 x ICC-4958 and BG-362 x RSG-931 under irrigated condition with a greater magnitude of dominance x dominance (l), indicating importance of dominance x dominance (l) for the inheritance of this trait.

3.10 100-seed Weight

Among the main effects, additive effect (d) was significant in all the crosses in both the conditions as well as in pooled analysis over environments (irrigated and rainfed) except RSG-895 x RSG-888 and CSJD-901 x RSG-931 under rainfed, whereas dominance (h) effect was non-significant in all the cases- indicating importance of additive effect in the inheritance of 100-seed weight. Among the interaction effects, additive x additive (i) effect was significant in all the crosses under both the conditions as well as in pooled analysis over environments, except in RSG-895 x RSG-888 and CSJD-901 x RSG-931 under irrigated, whereas dominance x dominance (l) effect was found non-significant in all the cases- indicating role of additive x additive (i) in controlling the inheritance of this trait.

3.11 Protein Content

The main effects additive (d) and dominance (h) were important for this trait, since both were significant in all the cases except for dominance (h) in RSG-888 x ICC-4958 in pooled analysis over environments and in IPC-94-94 x RSG-888 and CSJD-901 x RSG-931 under rainfed. Higher magnitude of dominance than additive effect in most of the cases indicated the greater role of dominance effect in the inheritance of this trait. Additive x additive (i) was significant in all the eight cases, however, dominance x dominance (l) was significant in only three cases under both the conditions including pooled analysis over environments-which indicated importance of additive x additive interaction for the inheritance of this trait.

In all the crosses under both the conditions, non-allelic interactions were predominant for most of the characters. The non-additive gene effects played greater role in the inheritance of all the characters under both the conditions except for 100-seed weight. Earlier Singh and Ramanujam (1981), Patil et al. (1987), Pandey and Tiwari (1989), Shinde and Deshmukh (1990), Mandal (1992), Girase and Deshmukh (2000), Mehla et al. (2000), Singh et al. (2001), Patil et al. (2004), Bhardwaj and Sandhu (2007), Gupta et al. (2006) and Gupta et al. (2007) also reported that both additive and non-additive gene actions for yield and yield contributing characters in chickpea.

4. Conclusion

In the present study non-additive gene effects *viz.,* dominance (h) and dominance x dominance (l) was controlling the expression of most of the characters under both the conditions and it is suggested that breeders should follow such methods which can mop-up the genes to form superior gene constellations interacting in a favorable manner. Hence, it is suggested that recurrent selection by way of intermating the desirable segregants followed by selection or biparental approach/intermating of segregants in early segregating generations for improvement of yield contributing characters should be followed.

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