Genetics of Yield and Yield Components in Chickpea (*Cicer arietinum* L.) under Irrigated and Rainfed Conditions

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By

Banwari Lal Kumhar

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Genetics of Yield and Yield Components in Chickpea (*Cicer arietinum* L.) under Irrigated and Rainfed Conditions

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Abstract **

The nature and magnitude of gene action, heterosis and inbreeding depression were studied for days to 50% flowering, days to maturity, plant height (cm), fruiting branches per plant, pods per plant, seeds per pod, biological yield per plant, seed yield per plant, harvest index (%), 100-seed weight (g) and protein content (%) in chickpea (*Cicer arietinum* L.) through generation mean analysis under irrigated and rainfed conditions. For this purpose, five generations (P_1, P_2, F_1, F_2 and F_3) derived from five crosses of chickpea *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 were grown at Research Farm, Agricultural Research Sub- Station, Hanumangarh, during *rabi* 2004-05 in Compact Family Block Design with three replications each under irrigated and rainfed conditions.

Analysis of variance revealed significant differences among all the crosses for all the characters under both the conditions. Significant differences were also observed among the generations of each of the five crosses for all the characters under both the conditions. Pooled analysis of variance revealed significant differences among environments (irrigated and rainfed) in all the crosses for all the characters except for seeds per pod in RSG-888 x ICC-4958 and BG-362 x RSG-931.The generation x environment interaction was also found significant in most of the cases for different characters. A comparison of mean values indicated a reduction under rainfed condition for all the characters except for protein content. It emerged that bold seeded parents *viz.,* ICC-4958, IPC-94-94 and BG-362 and the crosses involving bold seeded parents were least affected by moisture stress in rainfed condition.

Individual scaling tests revealed the presence of epistatic interactions in all the crosses for all the characters under both the conditions. The analysis of joint scaling test also confirmed the presence of epistatic interactions in all the five crosses for all the characters under both the conditions. On the basis of five parameter model, both the main effects *i.e.,* additive (d) and dominance (h) appeared important for all the characters in all the crosses under both the conditions with a greater magnitude of dominance (h) except for 100-seed weight, where only additive effect was found important. Among the interactions, both additive x additive (i) and dominance x dominance (l) interactions were important with a greater magnitude of dominance x dominance (l) in all the crosses for all the characters under both the conditions except for 100-seed weight, where only additive x additive (i) interaction was found important. Comparison of main effects and epistatic effects showed that epistatic effects played greater role in controlling the inheritance of all the characters studied under both the conditions.

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The absolute totals of fixable and non-fixable gene effects revealed the preponderance of non-additive gene effects in controlling the inheritance of all the characters under both the conditions except for 100-seed weight. Duplicate type of epistasis was present in all the cases, where epistasis was established.

In all the crosses, significant heterosis over mid parent was observed for all the characters under both the conditions except for seeds per pod. Heterosis over better parent (heterobeltiosis) was observed frequently in most of the crosses for most of the characters under both the conditions. Inbreeding depression was also common in most of the cases. The manifestation of heterosis was mainly due to dominance x dominance (l) followed by dominance (h) and additive x additive (i) components in most of the cases under both the conditions. Absence of heterosis occurred due to internal cancellation of heterotic components. The crosses RSG-888 x ICC-4958, BG-362 x RSG-931 and IPC-94-94 x RSG-888 had high mean values, heterobeltiosis with least inbreeding depression for most of the yield contributing characters under both the conditions, thus, could be utilized in future breeding programme.

As a consequence of higher magnitude of epistatic effects, the absolute totals of non-fixable gene effects were higher than fixable gene effects. Obviously, the successful breeding methods will be ones, which will exploit non-additive effects. Such methods are restricted recurrent selection, diallel selective mating, multiple crosses and bi-parental mating. Selection intensity should be mild in early and intense in the later generations because duplicate epistasis recorded in the material used in the present study might hinder the pace of progress to some extent during selection.

ABBREVIATIONS

1.	%	Per cent
2.	(d)	Additive
3.	(h)	Dominance
4.	(i)	Additive x additive
5.	(l)	Dominance x dominance
6.	ANOVA	Analysis of variance
7.	cm	Centimeter
8.	Env.	Environments
9.	g	Gram
10.	Gener.	Generations
11.	IRG.	Irrigated
12.	Pooled	Pooled analysis over environments
13.	Rep.	Replications
14.	RF	Rainfed

1. INTRODUCTION

Chickpea (*Cicer arietinum* L.) also known as Bengal gram or simply gram and as 'chana' in Hindi is a major *rabi* pulse crop. It is an autogamous annual herb belonging to sub family papilionaceae of the family leguminosae having chromosome number 2n = 16. It is believed to have originated in South-Western Asia and has been grown traditionally throughout the semi-arid regions of India and the Mediterranean.

Chickpea is the third most important pulse crop of the world (after dry bean and pea) cultivated over an area of 11.15 million hectares with production and productivity of about 8.58 million tonnes and 769 kg/ha, respectively (Anonymous, 2004). The most important chickpea growing countries are India, Pakistan, Turkey, Iran, Mexico, Myanmar, Ethiopia, Australia and Canada. India, ranks first in the world sharing 65 and 67 per cent of the total global area and production, respectively. In India, chickpea is cultivated on an area of 7.1 million hectares with production of 5.6 million tonnes and productivity of 795 kg/ha (Anonymous, 2006-07a). Major chickpea producing areas are concentrated in Madhya Pradesh, Rajasthan, Maharastra, Uttar Pradesh, Haryana and Punjab. In Rajasthan, the crop is cultivated mainly in the districts of Churu, Jhunjhunu, Bikaner, Hanumangarh, Sikar, Jaipur, Sriganganagar, Tonk, Nagaur and Ajmer occupies 10.11 lac hectares area and produces 8.73 lac tonnes of grain with a productivity of 864 kg/ha (Anonymous, 2006-07b).

Nutritionally, it is very rich as it contains about 17-21% protein, 62% carbohydrate and 5.3% fat. Chickpea is also rich in Ca, Fe, vitamin C (in green stage) and vitamin B_1. Cereal and chickpea proteins are nutritionally complementary, the amino acids which are deficient in one being generally adequate in other. The P.E.R (protein efficiency ratio) value of chickpea seems to be the highest among grain legumes. It is used in many forms as 'dal', 'chhole' and 'besan' (gram flour). Gram flour is used for the preparation of sweets, snacks and many attractive dishes. Its leaves contain mallic and citric acid, which are very useful for stomach ailments and blood purification. It's straw is highly rich in nutrients and mostly used as productive ration for animals.

Chickpea is adversely affected by several biotic stresses such as diseases *viz*., *Fusarium* wilt, gray mould and *Ascochyta* blight, and insect pests, mainly pod borer (*Helicoverpa armigera)* and abiotic stresses. Because of these factors the area under chickpea has declined considerably (Anonymous, 2007). Scope of increasing production lies in thorough understanding of chickpea ideotype and increasing biomass production, harvest index and insect resistance, resistance to drought, salinity and alkalinity, etc.

Chickpea is generally cultivated as a rainfed crop during post rainy season on the residual and receding soil moisture condition in the Indian subcontinent. Two thirds of the total area under chickpea is rainfed, hence drought is the single most important abiotic stress, which severely affects the productivity of chickpea under rainfed production system. Significant variation among genotypes for yield and yield contributing characters under moisture stress condition in chickpea has been observed by Kamble *et al.* (1984), Singh *et al.* (1997), Kanouni *et al.* (2002), Durga *et al.* (2003), Sanap *et al.* (2004), Kumar *et al.* (2004), Dhiman *et al.* (2006) and Meena *et al.* (2006).

To achieve higher yields in both favourable and harsh environments, attempts should be made to explore and exploit the novel genes of desirable traits through systematic breeding programmes by involving diverse cultivars. The choice of plant breeding methodology for upgrading the yield potential largely depends on the availability of reliable information on the nature and magnitude of gene effects present in the population. A number of methods in quantitative genetics are available to estimate different genetic components *viz*., additive, dominance and epistatic interactions. The reports on inheritance studies conducted in chickpea have mostly been made following diallel mating design (Katiyar *et al.*, 1980, Deshmukh and Bhapkar, 1982a and Bhanushally, 1984), which does not provide information on the non-allelic gene interactions involved. The non-allelic gene interactions could inflate the measures of additive and dominance components. The role of non-allelic interaction besides additive and dominance was also realized quite early by Hayman (1958), Brim and Cockerham (1961), Gamble (1962), Matzinger (1968) and Stuber and Moll (1974). Jinks (1955) ascribed the manifestation of heterosis mainly to the epistatic interaction. It is therefore, important to detect and estimate the components of epistasis along with additive and dominance components.

Generation mean analysis provides the estimates of main components of gene action (*i.e*., additive and dominance) and their interactions. Moreover, the information on genetic architecture of yield and its contributing characters in chickpea using generation mean analysis are very limited under semi-arid rainfed environment. Obviously, knowledge of genetics of yield and its attributes and their inheritance under irrigated and rainfed conditions using generation mean analysis is definitely required which will help the breeders in planning of suitable strategy for developing improved chickpea varieties suitable for drought environment with reasonable good yield potential and other desirable traits. Chickpea is a self-pollinated crop and the scope for exploitation of hybrid vigour will depend on the direction and magnitude of heterosis and type of gene action involved. The study of heterosis and inbreeding depression will have a direct bearing on the breeding methodology to be employed for varietal improvement.

With this background the present investigation was undertaken with the following objectives:

1. To estimate the relative magnitude of different types of gene effects and their interactions for yield and its components in chickpea under irrigated and rainfed conditions.
2. To estimate degree of heterosis and inbreeding depression for metric characters in chickpea crosses grown in different environments (both irrigated and rainfed).
3. To suggest a suitable breeding strategy on the basis of results achieved for the improvement in chickpea.

2. REVIEW OF LITERATURE

Chickpea (*Cicer arietinum* L) is a major pulse crop in the world. The harsh environmental conditions (rainfed/drought) under which chickpeas are generally grown impose restrictions on the expression of genetic yield potential. As it is a very important pulse crop in India, the efforts were and are being made by the scientists from time to time to improve its productivity. The informations available on the genetics of yield and yield contributing attributes in chickpea, which is of fundamental importance in devising breeding methods, are very scanty and particularly very limited under semiarid/ rainfed/ drought environment. The available literature on the genetics of yield and yield attributes in chickpea is reviewed in this chapter along with a general review on the methods used in quantitative genetics to obtain information on the above aspects.

2.1 Response of chickpea to moisture stress/rainfed environment

Rainfed means growing of crops without irrigation on soil with declining moisture conserved from rains received prior to growing season. Chickpea is raised during post rainy winter season on a residual and receding soil moisture condition where the crop is exposed to terminal drought and heat stress causing reduction in grain yield.

Cessation of irrigation at flowering induced a rapid decrease in canopy photosynthesis and reduced the grain yield up to 33% due to a decrease in the number of pod set. Irrigation from 120 DAS resulted in some recovery of grain yield resulting from the development of a small number of late pods with small seeds. Among yield components, water stress primarily affected the number of pods per plant and had little effect on the grains number per pod (Singh *et al.,* 1978).

High air temperatures during the period from flowering to maturity reduces the time to maturity of late sown chickpea and leads to reduced seed size and lower yields (Siva Kumar *et al.,* 1987).

India realizes the yield of chickpea to about half of what could be achieved with supplementary irrigation. Development of short duration genotypes of chickpea has increased options of escaping terminal drought stress (Chauhan *et al*., 1989).

Calcagno and Gallo (1993) suggested that in hot environment, early flowering, quick maturation and the efficient distribution of dry matter between the root of the plant and the seeds are required.

Singh (1997) suggested that ideotype for late sown rainfed condition in north India should possess early vigour, a plant height of 50-60 cm, 60-70 pods per plant, 2-3 primary branches, 9-10 secondary branches, about 2 seeds per pod and a 1000-seed weight of 200-250g. He also suggested that bold seeded lines (1000-seed weight $>$200g) gave higher yields in trial conducted in late sown rainfed conditions. Later, he also reported that genotypes with early vigor, early maturity, high harvest index and relatively few branches would perform best in the drought condition.

Kumar *et al.* (2004) observed that biomass production was highly affected by moisture stress; in general, bold seeded genotypes showed greater biomass production than medium bold seeded genotypes. The seed weight and number of seeds per pod were not significantly affected by moisture stress. He also revealed that under moisture stress, seed yield was governed by the number of branches and pods per plant, biomass and harvest index, thus these traits should be given importance during breeding for drought tolerance.

Lama and Chakravarty (2004) revealed that under unirrigated conditions, the phenological events were earlier in all the varieties as compared to irrigated conditions. The unirrigated crop matured 7-10 days earlier.

Muhammad *et al.* (2004) revealed that biological yield and harvest index had high direct effect on grain yield under rainfed conditions. Most of the yield components had high

indirect contribution on grain yield via biological yield; thus, biological yield and harvest index should be given more consideration while deciding selection criteria for rainfed conditions.

Ozgun *et al.* (2004) observed that irrigation increased days to maturity, pod length, pod width, seed roughness, number of secondary branches per plant, biological yield per plant, number of filled pods per plant, number of seeds per plant, seed yield per plant, 100-seed weight, grain yield per plant, total biological yield, hay yield per unit area and harvest index.

Sanap *et al.* (2004) observed that the average grain yield reduced 35.73% from well-irrigated condition to under drought condition in chickpea.

Yadav *et al.* (2004) observed that the bold seeded *desi* genotypes gave superior performance in the rainfed environment, while the bold seeded *kabuli* genotypes out yielded the other cultivars under supplemental irrigation.

Dhiman *et al*. (2006) investigated changes in morphological and physiological parameters in 50 chickpea genotypes under rainfed conditions. The study showed significant genotypic differences for yield attributes under rainfed and irrigated conditions. Under rainfed conditions, the plant height was comparatively less. Productive branches in *desi* and *kabuli* genotypes decreased by 17% and 25% under rainfed conditions. There was a delay of 10-12 days in flowering of all the genotypes, and 20 and 10 days in maturity of *desi* and *kabuli* genotypes under irrigated conditions. 100-seed weight was more or less constant under both the conditions. *Kabuli* genotypes registered much higher increases for productive pods, seed yield and biological yield under irrigated conditions as compared to *desi* genotypes. The reduction in harvest index was noticed under irrigated conditions in general. The *desi* cultivars were more suitable for rainfed conditions and *kabuli* cultivars for irrigated conditions.

Sharma *et al.* (2007) revealed that most of the yield attributes along with seed yield, biological yield and harvest index decreased significantly with increased moisture stress.

Research work done so far conclusively prove that the yield of chickpea is significantly higher under irrigated conditions than under rainfed situations. Though the protein content is slightly higher under rainfed situation but it cannot compensate to the difference in protein yield under irrigated condition.

2.2 STUDIES ON COMPONENTS OF VARIANCE AND GENE EFFECTS

Plant breeders are primarily interested in improving yield by developing superior varieties. This can be achieved by altering the genetic make up of existing varieties. The phenotypic expression of yield and most of the other characters of economic importance is quantitative in nature and their inheritance not only involves large number of genes with small individual effects, but these genes also interact themselves in a complex manner and are highly influenced by environment. According to Smith (1944) typical quantitative characters were determined by a large number of genes, some times referred to as polygenes (Mather, 1943) having small individual effects and acting in cumulative manner.

Two classical experiments of Scandinavian geneticists (Johannsen, 1909 and Nilsson-Ehle, 1909) explained that similar factors of smaller individual action could account for continuous variation. Each of these factors would follow the similar mendelian inheritance pattern.

Fisher (1918) carried the integration of biometry and genetics and partitioned the genotypic variance into three logical components namely, (i) average effects of genes (additive genetic variance) (ii) allelic interactions of segregating genes (dominance variance) and (iii) non-allelic interactions of segregating genes (epistatic variance). Wright (1935) termed these as (i) additive genetic variance (ii) variance due to dominance deviation and (iii) variance due to epistatic deviation, respectively.

Fisher *et al.* (1932) presented a method for estimation of degree of dominance. Mather (1949) partitioned genetic variance into fixable (D) and non-fixable (H) components assuming no epistasis in F_2, F_3 and back cross generations derived from two homozygous parents.

Several other eminent biometricians like Wright (1921), Haldane (1932), Cockerham (1954), Kempthorne (1957), Rawling and Cockerham (1962), Gardner (1963), Dudley and Moll (1969) and Mather and Jinks (1971) have made commendable contribution in the partitioning of total genetic variance.

Further, the epistatic variance was partitioned into factorial components of digenic and higher order interactions *viz*., additive x additive, additive x dominance and dominance x dominance for two loci by Cockerham (1954). Kempthorne (1955) partitioned the heritable variance into different components as :

$\sigma^2 G = \sigma^2 A + \sigma^2 D + \sigma^2 AA + \sigma^2 AD + \sigma^2 DD + \sigma^2 AAA + \sigma^2 AAD + \sigma^2 DDD$ and so on.

2.3 Methodology of genetic analysis

Biometrical techniques were developed to provide information on the level of genetic variability and type of gene actions based on either partitioning of means that provides estimates of gene effects using first degree statistics or partitioning of variances and covariances to estimate the components of genetic variation using second degree statistics (Sharma, 1986). Different statistical models have been proposed for obtaining precise and unbiased estimates of fixable and non-fixable components of genetic variation such as partitioning of total variance into its components (Fisher *et al.,* 1932, Powers, 1942 and Mather, 1949), variance and covariance analysis of parents and progenies (Comstock and Robinson, 1952), diallel cross analysis (Jinks and Hayman, 1953, Jinks, 1954 and Hayman, 1954, 1957, 1958) and generation mean analysis (Jinks and Jones, 1958, Hayman, 1954 and Mather and Jinks, 1971). Out of different approaches outlined here generation mean analysis bears the merit of providing complete information about genetic components of variation including epistasis and gives statistically robust results based on first-degree statistics.

2.3.1 Generation mean analysis

Mather (1949) was first to envisage a three parameter model and described the effect of gene differences on the phenotypic expression by two parameters *i.e.,* additive (d) and dominance (h) with 'm' being mid-parent value. Considering epistasis not important, he suggested transformation of scale to fit the data of this non-epistatic model.

The scale appropriate for one population may not be appropriate for another and scale appropriate to genetic and environmental components of variation may be different (Powers, 1951). Further, Mather (1949) and Hayman and Mather (1955) proposed 'A', 'B', 'C' and 'D' scales in order to determine the presence or absence of gene interactions. Cavalli (1952) proposed a joint scaling test for estimating parameters, m, (d), and (h) with the help of weighted least square technique which was based on four or more number of families and to test the adequacy of the additive-dominance model by chi-square technique. A detailed treatment of relationship between scale and epistatic interaction is given by Horner *et al.* (1955). They concluded that a transformation, which reduced interaction variance, might be useful, if conclusions were to be drawn from an analysis that depends on its validity in the absence of interaction.

Genetic models permitting the estimation of epistatic effects were developed by Anderson and Kempthorne (1954), Cockerham (1954) and Hayman and Mather (1955). These models were based on the factorial model used in the design of experiments. Anderson and Kempthorne's model employed the mean of population obtained from crossing two homozygous lines followed by subsequent crossing and selfing. They showed that all information about additive, dominance and digenic variation available in the means of generations is contained in six parameters, namely, K_2, E, F, G, L and M. Some of these are not easily interpreted due to gene effects in the parameters, whereas, Hayman (1958) described parameters m, (d), (h), (i), (j) and (l). Gamble (1962) used different notations *i.e.,* m, a, d, aa, ad, and dd from the means of six basic generations to represent various gene effects given by Hayman (1958), who used similar technique in maize.

Hayman and Mather (1955), Hayman (1958) and Jinks and Jones (1958) described the methods of estimation of contribution of non-allelic interactions between pairs of genes to generation means. They used parents, F_1s, F_2s and first back cross generations (BC_1 and BC_2) to estimate six genetic parameters. According to Hayman (1958) the six parameters are estimated as:

$$m = \bar{F}_2$$

$$(d) = \bar{B}_1 - \bar{B}_2$$

$$(h) = \bar{F}_1 - 4\ \bar{F}_2 - (1/2)\ \bar{P}_1 - (1/2)\ \bar{P}_2 + 2\ \bar{B}_1 + 2\ \bar{B}_2$$

$$(i) = 2\ \bar{B}_1 + 2\ \bar{B}_2 - 4\ \bar{F}_2$$

$$(j) = 2\ \bar{B}_1 - \bar{P}_1 - 2\ \bar{B}_2 + \bar{P}_2$$

$$(l) = \bar{P}_1 + \bar{P}_2 + 2\ \bar{F}_1 + 4\ \bar{F}_2 - 4\ \bar{B}_1 - 4\ \bar{B}_2$$

Hayman (1958) also suggested five-parameter model to estimate components of means (gene effects) for digenic control of a trait when backcrosses are not available and instead F_3 data are available. In this model five parameters *viz.,* m, (d), (h), (i) and (l) are estimated as follows:

$$m = \bar{F}_2$$

$$(d) = 1/2 (\bar{P}_1 - \bar{P}_2)$$

$$(h) = 1/6(4 \bar{F}_1 + 12 \bar{F}_2 - 16 \bar{F}_3)$$

$$(i) = \bar{P}_1 - \bar{F}_2 + 1/2(\bar{P}_1 - \bar{P}_2 + h) - 1/4 l$$

$$(l) = 1/3 (16 \bar{F}_3 - 24 \bar{F}_2 + 8 \bar{F}_1)$$

Toledo *et al.* (1991) suggested that the five parameter model was good as the back cross studies for estimation of gene effect and gives satisfactory results.

Jinks and Jones (1958) proposed a method of estimation of components of generation means together with components of heterosis. Mather and Jinks (1971) presented the relationships for digenic interactions to estimate the components of heterosis in absence of backcrosses, using F_3 data.

2.3.2 Variance analysis

Analysis of genetic variance applying second degree statistical method into components like additive and non-additive and of the later into dominance and epistatic variances lead to devising appropriate selection methods as well as the breeding methods in a crop. A number of methods have developed which enable a breeder to obtain estimate of the components of the genetic variance.

The frequently adopted ones are:

(1) Co-variance of half sib and full sibs (Comstock and Robinson, 1948 and 1952)

(2) Diallel cross analysis (Hayman, 1954)

(3) Line x tester analysis (Kempthorne, 1957)

(4) Combining ability analysis (Sprague and Tatum, 1942, Griffing, 1956 etc)

These methods were developed on the principles given by Fisher (1918 and 1932).

2.3.3 Gene effects

The knowledge of gene effects is very useful in formulating the efficient breeding method suited to particular crop and material and there by accelerate pace of its genetic improvement. The gene effects besides being dependent on the material selected are also influenced by the environment. An attempt has been made to review earlier studies on gene effects for different characters in chickpea as under:

Gowda (1975) found that the additive component was more important for seed size, days to flowering and plant height, while non-additive component for branch number and number of seeds per pod. For pods per plant, both the components were significant. For most of the characters the dominance component in F_2 was approximately half of that of F_1 generation.

Katiyar (1975) reported the preponderance of dominant component for primary branches, additive component for seeds per pod and seed size, while both were significant in pods per plant.

Singh (1976) observed that in respect of yield and pods per plant non-additive gene action was predominant, while seed size, days to flowering, days to maturity and seeds per pod were under additive genetic control.

Tomar (1976) while studying F_1 and F_2 generations recorded the preponderance of additiveness in pods per plant, seeds per pod, seed size. Seed yield and primary branches per plant indicated the prevalence of dominant gene action, while secondary branches was governed by both the components (D and H).

Maheshwari (1978) observed that additive component was of greater magnitude for days to flowering, days to maturity and seed size, while dominance component was important for primary branches, secondary branches, plant height and seeds per pod. For pods per plant, seeds per plant and yield per plant, both additive and dominance components were equally important.

Pandey *et al.* (1980) studied the F_1 diallel of 9 lines of chickpea and reported the importance of both additive and non-additive type of gene actions for the expression of yield.

Singh and Mehra (1980) carried out genetic analysis of yield and yield components in Bengal gram using seven parents and their 21 F_1s. The results indicated that 100-seed weight, days to flowering and days to maturity were mainly governed by additive and additive x additive gene effects, while genetic control for yield and its primary components *viz.,* fruiting branches per plant, pods per plant, seeds per pod and harvest index was both additive and non-additive in nature.

Singh and Ramanujam (1981) carried out generation mean analysis for mean quantitative characters from the parents, F_1, F_2 and F_3 for four chickpea crosses. The results indicated that both additive and non-additive gene effects were important for all the characters studied *viz*., plant height, primary branches per plant, days to flowering, days to maturity, pods per plant, seeds per pod, seed size, seed yield and harvest index. The contribution of additive component was pronounced particularly for days to flowering, days to maturity, pods per plant and seeds per pod.

Malhotra *et al.* (1983) revealed that both additive and non-additive type of gene actions were important for seed yield, 100-grain weight, seeds per pod and pods per plant with preponderance of additive type of gene action. However, for number of primary and secondary branches only additive type of gene action was present.

Salimath and Bahl (1985) reported that both additive and non-additive variances were important for days to first flowering, where the former was more predominant. For days to maturity, only non-additive variance was significant.

Patil *et al.* (1987) studied inheritance of fruiting branches per plant, pods per plant, yield per plant, 100-seed weight, days to maturity and protein content in three crosses of chickpea using scaling test with six-generation means and found the involvement of epistatic gene action in fruiting branches per plant, pods per plant, yield per plant, 100-seed weight, days to maturity and protein content in most of the crosses. In all the three crosses dominance gene action was involved in the inheritance of pods per plant. The duplicate epistasis was predominating in most characters in most crosses. Only one cross indicated sufficient additive gene effects for yield and its components suggesting the possibility of improvement through selection.

Kidambi *et al.* (1988) studied three crosses of chickpea each having seven generations *i.e.,* P_1, P_2, F_1, F_2, B_1, B_2 and F_3 using generation mean analysis to estimate the genetic components. The results showed genetic differences in all three crosses for all the traits studied *viz.,* days to flowering, days to maturity, plant height, primary branches and secondary branches. Additive, dominance and epistatic effects were found for days to flowering, days to maturity, plant height, number of primary branches and number of secondary branches. Duplicate epistasis was observed for all traits except number of primary branches.

Salimath *et al.* (1988) estimated non-additive genetic variation to influence the inheritance of seed protein content.

Pandey and Tiwari (1989) estimated the nature and magnitude of digenic allelic interactions involved in the expression of yield and its components by generation means under two environments. The results showed that plant height, primary branches and secondary branches inherited by simple additive and dominance gene effects in all the crosses. While, both additive and non-additive gene effects (dominance and epistasis) were important for flowering and maturity in majority of the crosses.

Shinde and Deshmukh (1990) carried out scaling test with five generation means in five crosses of chickpea to elucidate the type of gene action involved in the expression of yield and its contributing characters. The results indicated that epistatic gene actions were involved in the expression of fruiting branches per plant, pods per plant, 100-grain weight, yield per plant and days to maturity. In all the five crosses dominance gene action was involved for all the characters *i.e.,* fruiting branches per plant, pods per plant, yield per plant and days to maturity except for 100-grain weight. In most of the crosses, additive gene action was involved in the inheritance of 100-seed weight. But additive and dominance gene effects, dominance x dominance and additive x additive interactions were important for all the yield components. Dominance effects followed by interactions and additive component played a significant role in the inheritance of grain yield. Duplicate epistasis was more predominant.

Malhotra and Singh (1991) studied six crosses of chickpea using combining ability and generation mean analysis for reaction to cold. The generations mean analysis revealed the presence of genic interactions in addition to additive and dominance gene effects. Among the interactions, additive x additive and dominance x dominance with duplicate epistasis were present.

Mandal (1992) found that inheritance of harvest index was controlled primary by dominant gene action.

Singh *et al.* (1994) carried out generation mean analysis and revealed that seeds per pod was mainly conditioned by additive gene effects and their first-order interactions.

Kumar and Singh (1995) studied inheritance of seed size in chickpea in two desi x desi crosses using six-generation means. The results indicated that small seed size was partially dominant over large seed size and major contribution to genetic variation in these crosses came from additive gene effects.

Annigeri *et al.* (1996) revealed the predominance of additive variance for pods per plant and seeds per pod and both additive and non-additive variances for 100-seed weight and seed yield per plant through a seven parent diallel analysis.

Jha *et al.* (1997) found that days to flowering, primary branches, secondary branches, pods per plant and seeds per pod were predominantly under the control of additive genetic effects, while for 100-seed weight and yield per plant both additive and dominance gene effects were equally important.

Malhotra *et al.* (1997) carried out combining ability and generation mean analysis. The results showed that both additive and non-additive gene effects were important with the preponderance of additive gene action for seed size

Patil *et al*. (1998a) studied the inheritance of yield and yield components in desi x desi (D x D), desi x kabuli (D x K) and kabuli x kabuli (K x K) crosses of chickpea using generation mean analysis. Predominance of epistatic gene action was observed for secondary branches, number of pods, seeds per pod and seed yield in all the crosses. However, for primary branches, test weight and seeds per pod additive gene action was important in D x D and D x K crosses. For primary branches in K x K crosses dominance component was more important. D x D and K x K crosses also showed significance of additive component for number of pods and seed yield but in D x K cross it was non-additive.

Kumar *et al.* (1999) carried out genetic analysis for different components of crop duration in 6 accession and 15 F_1 hybrids of chickpea. The results indicated that additive and non-additive gene actions were involved in the inheritance of days to first flower, days to first pod, days to maturity, total reproductive period, pod establishment period and pod filling period with additive gene effect being predominant in the expression of the days to first flower, days to first pod, days to maturity and non-additive gene effects for the total reproductive period, pod establishment period and pod filling period.

Girase and Deshmukh (2000) carried out generation mean analysis involving nine generations of each of the three crosses in chickpea to elucidate the inheritance of days to flowering, days to maturity, plant height, fruiting branches per plant, pods per plant, seeds per pod, 100-seed weight and yield per plant. The results indicated that both additive and non-additive gene actions were involved in the inheritance of most of the studied characters. Duplicate type of gene action was involved in the expression of days to flowering, days to maturity, fruiting branches per plant and 100-seed weight. These observations imply the use of biparental approach/intermating of segregants in early segregating generation for improvement in grain yield.

Mehla *et al.* (2000) carried out generation mean analysis involving six basic generations of 3 crosses of *kabuli* gram to elucidate the inheritance of plant height, primary and secondary branches, pods per plant, seeds per pod, seed yield and 100-seed weight. The relative magnitude of additive effect (d) and additive x dominance (j) was, in general more than the dominance effect (h) and additive x additive (i). The dominance x dominance (l) effect was present in majority of crosses for different characters under study. The detection of both fixable and non-fixable gene action and of duplicate epistasis implies the use of biparental approach/intermating in early segregating generations.

Sarode *et al.* (2000) revealed the predominance of non-additive gene action for all the characters studied *i.e.,* basal branches per plant, secondary branches per plant, pods per plant and seed yield per plant except 100-seed weight.

Singh *et al.* (2001) studied the inheritance of important agronomic traits in segregating population of F_1, F_2 and F_3 generations of 4 chickpea crosses through generation mean analysis by following the five-parameter model of Hayman (1958). The results revealed that most of the quantitative traits are controlled by both additive and non-additive type of gene action. In such situation population improvement approach for genetic improvement of agronomic traits would be advantageous.

Bhaduoria *et al.* (2002) carried out generation mean analysis involving six generations of each of ten crosses derived from genetically diverse parents to determine the inheritance of grain yield and its components in chickpea. Both additive and non-additive gene effects were involved in the inheritance of most of the characters. Majority of the crosses displayed dominance effect for grain yield. Only two crosses showed significant and positive additive gene effect for grain yield per plant. These results suggest the use of bi-parental mating or intermating of segregants from early segregating generations for the improvement in grain yield in chickpea.

Patil *et al.* (2004) carried out diallel analysis using seven parents of chickpea. The results revealed that additive type of gene action was found important for plant height, secondary branches per plant and 100-seed weight. However, non-additive gene action was involved in inheritance of grain yield per plant, days to 50% flowering, pods per plant and harvest index.

Gupta *et el.* (2006) made diallel analysis for yield and other quantitative traits in *desi* chickpea and observed predominance of additive gene effect for

plant height and 100-grain weight and non- additive gene effect for harvest index. Both additive and non-additive gene effects were important for number of branches per plant, pods per plant, grains per pod, grain yield per plant and biological yield per plant.

Bhardwaj and Sandhu (2007) estimated the gene actions operating in the inheritance of days to flowering, pod initiation, days to maturity, plant height, branches per plant, pods per plant, seeds per pod, grain yield per plant, harvest index and 100-seed weight in two crosses each having six basic generations *viz*., P_1, P_2, F_1, BC_1, BC_2 and F_2. Significant χ^2 values indicated higher order of interaction for all traits except grain yield per plant for C_2. Generally, the dominance component was higher in magnitude than additive component in all the traits except for days to maturity (C_1), pods per plant (both crosses), grain yield per plant (C_2). Duplicate type of epistasis was present in most of the cases.

Gupta *et al.* (2007) performed 6 x 6 diallel analysis in *kabuli* chickpea for yield and other quantitative traits. The results indicated predominance of additive gene effect for plant height and non-additive gene effects for number of branches per plant, pods per plant, grains per pod, 100-seed weight, grain yield per plant, biological yield per plant and harvest index.

Hegde *et al.* (2007) carried out line x tester analysis to acquire an understanding of the predominant type of gene action governing biomass (BY) and harvest index (HI). The results indicated the predominant role of additive action on BY and HI

2.3.4 Heterosis and inbreeding depression

Hybrid vigor was first reported by Koelreuter in 1763 according to East and Hayes (1912). Bruce (1910) thought that a combined action of favorable dominant or partially dominant factors causes heterosis. The concept of heterozygosity, linkage and interaction of alleles at same locus as causes of heterosis was introduced by East and Hayes (1912). The term heterosis was coined by Shull (1914). Heterosis, a quantitative genetic terminology usually measured as the superiority of a hybrid over the average performance of the parents or better parent. This genetic expression is used generally in terms of beneficial effects of hybridization. Fonseca and Patterson (1968) coined a new term “heterobeltiosis” to describe the improvement of heterozygote in relation to better parent.

In the recent past, plant breeders have extensively explored and utilized heterosis in boosting up yield in a number of crops like maize, sorghum, pearl millet and cotton. Chickpea being a highly self-pollinated crop, scope for exploitation of hybrid vigour will depend on the direction and magnitude of heterosis, biological feasibility of the crop and nature of gene action. Exploitation of heterosis on a commercial scale through hybrid seed production although theoretically possible, may not be achieved on a practical scale in this crop because of cleistogamous nature of the flower and lack of male sterile line. Chickpea breeder has to concentrate his attention upon the conservation of additive component of genetic variance and those epistatic interactions, which can be exploited in homozygous state to isolate superior lines from crosses showing high heterosis. Paroda and Joshi (1970) advocated that the avenues for the exploitation of high specific combining ability effects would be in cross

combinations where the F_1 means are superior to the best parental variety or best local variety included in the experiment, also when inbreeding depression from F_1 to F_2 is such that the F_2 mean is either superior to or at par with the best parental variety included in the experiment. Thus, cross combinations having high heterobeltiosis and standard heterosis but low inbreeding depression may be exploited for high sca effects. This situation, would be expected to operate particularly in cross combinations involving genetically distinct parents which show high general combining ability effects and when the fixable genetic component of variation is present in sizable proportion. The information available on heterosis and inbreeding depression in chickpea is reviewed as under:

Gupta and Ramanujam (1974) observed heterosis in chickpea for grain yield and reported 122 percent higher grain yield in hybrid than the better parent.

Gowda and Bahl (1976) concluded that heterosis for yield was the result of heterosis for pods per plant and number of branches per plant. For seed size, majority of the crosses showed negative heterosis.

Singh (1976) revealed that the heterosis in yield was mainly due to heterosis in pod number. For seed size none of the crosses gave higher value in comparison to high parent.

Singh and Singh (1976) observed that 94 percent of F_1's exhibited heterosis for grain yields over mid parent in Bengal gram. The magnitude of heterosis observed over mid parent was 98.61 percent, while over better and best parent it ranged up to 62.24 and 4.87 per cent, respectively. Most of the hybrids expressed negative heterosis for 100 seed weight.

Maheshwari (1978) observed marked heterosis over various yield components *viz*., primary branches per plant, pods per plant, seeds per plant and yield per plant.

Deshmukh and Bhapkar (1979) studied the performance of 36 F_1s involving chickpea varieties of diverse origin for heterosis over better parent for grain yield and four physiological components *viz.,* leaf area index, crop growth rate, relative growth rate and net assimilation rate.

Bhatt and Singh (1980) studied the magnitude of heterosis for yield and its three components. The maximum values for heterosis over the mid parent and better parent were 70.0 and 70.0 per cent for primary branches per plant, 62.2 and 40.7 per cent for pods per plant, 25.1 and 19.6 per cent for seeds per pod and 188.9 and 168.0 per cent for yield per plant, respectively.

Katiyar *et al*. (1980) found positive heterosis for pod length and width. Singh and Mehra (1980) observed the significant heterosis over better and best parent in all yield components *i.e.,* plant height, branches per plant, pods per plant, seeds per pod, 100-seed weight, single plant yield, harvest index in different chickpea crosses.

Kunadia and Singh (1980) studied heterosis and inbreeding depression in 8 x 8 diallel cross of *kabuli* gram and found positive as well as negative heterosis for all the characters.

Heterosis for yield was as high as 83.5 percent over mid parent and 60.2 percent over better parent. Most of the crosses showing heterosis for yield and pods per plant also exhibited high inbreeding depression.

Singh and Ramanujam (1981) observed 24.4% and 13.7% heterosis for yield over mid parent and the best parent in chickpea, respectively. Inbreeding depression was significant for pods per plant in two crosses, where significant heterosis for pod number was observed in F_1.

Deshmukh and Bhapkar (1982a) reported 139.4 and 113.8 per cent heterosis over the better parent for seed yield and number of pods per plant in chickpea, respectively.

Desmukh and Bhapkar (1982b) observed heterosis over better parent ranged from 27.28 per cent for grains per pod to 111.31 per cent for pods per plant. Maximum beneficial heterosis for grain yield was observed in Phule G-5 x Annegiri (72.11 %). In general, hybrids showing high heterosis also showed inbreeding depression.

Bhanushally (1984) observed appreciable amount of heterosis (183.39%) and heterobeltiosis (152.63%) for yield per plant. For most of yield components *viz*., pods per plant, branches per plant, seeds per plant, seed size, plant height, significant heterosis and heterobeltiosis was reported.

Salimath and Bahl (1985) observed significant heterosis for days to flowering and days to maturity over better parent.

Tewari and Pandey (1987) observed positive heterosis over better parent for pods per plant, seeds per plant, seed yield, 100-seed weight and seeds per pod in chickpea crosses. In general, hybrids showing high heterosis also showed high inbreeding depression.

Salimath *et al.* (1988) observed significant and positive heterosis over mid parent and better parent for seed protein content in different chickpea crosses.

Pandey and Tiwari (1989) observed significant positive heterosis over better parent for days to flowering, days to maturity, plant height, branches per plant, pod number, seed number and yield. The maximum heterosis (29.02% and 16.76%) associated with maximum inbreeding depression for yield was noted in one out of five crosses. They also reported negative heterosis for days to maturity and 100-seed weight in some crosses.

Rao and Chopra (1989) found high heterosis and heterobeltiosis for yield per plant, number of primary branches, number of secondary branches, plant height, number of pods per plant and seed weight in most of the crosses.

Katiyar and Katiyar (1993) found that out of fifteen F_1 hybrids studied, eleven crosses showed significant heterosis for seed yield.

Patil *et al.* (1998b) evaluated three crosses of chickpea (D x D, D x K and K x K) and the results showed high mid-parent heterosis for number of seeds, plant height, number of primary branches and better parent heterosis for plant spread and internode distance. D x D crosses showed higher mid parent heterosis for secondary braches only. D x D crosses also showed higher better parent heterosis in desirable direction for morphological traits and seed yield.

Jeena and Arora (2000) evaluated twenty-four F_1s for yield and its components in chickpea. The heterosis over mid parent and over better parent was estimated for all the trails. It was also revealed that crosses having high mean performance always exhibited high heterosis in the desired direction for almost all the characters except for pods per plant.

Sarode *et al.* (2000) reported good amount of heterosis both over mid parent and better parent for seed yield per plant, pods per plant and number of secondary branches per plant. However, for 100-seed weight and number of basal branches per plant only mid parent heterosis was observed.

Singh *et al.* (2000) estimated high heterosis over better parent and mid parent for seed yield per plant and pods per plant in most of the crosses. The trend of average inbreeding depression for yield per plant and other characters was similar to that of heterosis but lower in magnitude.

Sharif *et al.* (2001) studied F_1 hybrids between 14 chickpea cultivars for heterosis and heritability estimates for various traits. The high heterotic effects were recorded for branches per plant, biological yield, pods per plant, grain yield and plant height.

Singh *et al.* (2002) found that positive heterosis was highest for number of pods per plant (114.5%) followed by grain yield per plant (73.33%). For grain yield out of ten hybrids, seven gave positive heterosis over better parent. Maximum inbreeding depression for grain yield was 56.20%, while maximum negative inbreeding depression was (-13.00%).

Bhaduoria and Chaturvedi (2003) estimated heterosis and inbreeding depression in 10 crosses of chickpea for eight parameters *i.e.,* days to first flower, days to 50% flowering, plant height, days to maturity, number of pods per plant, number of seeds per pod, seed yield per plant and 100-seed weight. A range of significant heterosis and inbreeding depression was observed for various traits in different crosses.

Gupta *et al.* (2003) studied seven crosses of desi x desi and nine crosses of desi x kabuli to estimate the extent of heterosis over better parent and standard variety for grain yield, number of pods per plant and 100-seed weight. High heterosis was observed for yield per plant and 100-seed weight over desi parent and only for yield per plant over kabuli parent

in desi x kabuli crosses. The number of pods per plant was positively heterotic in all hybrids that had high heterosis for seed yield per plant.

Hegde *et al.* (2007) evaluated 30 F_1s obtained by crossing ten adapted genotypes as females to three testers as males in a line x tester design. A large number of crosses showed positive and mid-parent heterosis (MPH) and better-parent heterosis (BPH). The average MPH and BPH for biomass yield (BY) was 22.36 and 12.65, respectively and the average MPH and BPH for the harvest index (HI) was 2.22 and –0.92, respectively. The higher magnitude of the MPH and BPH recorded for BY indicated that further increase in productivity have to come mainly through enhanced BY.

It is obvious from the foregoing account that genetic studies like nature and magnitude of gene actions, heterosis and inbreeding depression are of paramount importance in the crop improvement. The reports on inheritance studies conducted in chickpea have been mostly been made following diallel mating design, which does not provide information on the non-allelic gene interactions involved, moreover, such studies are scanty and particularly limited under semi-arid rainfed environment. Therefore, the present study may provide the needed information in planning suitable breeding strategies for chickpea improvement.

3. MATERIALS AND METHODS

The present investigation entitled “Genetics of yield and yield components in chickpea (*Cicer arietinum* L.) under irrigated and rainfed conditions” was conducted during *rabi* 2004-05 at Research Farm, Agricultural Research Sub Station, Hanumangarh.

3.1 EXPERIMENTAL MATERIAL

The experimental material consisted of five generations namely, P_1, P_2, F_1, F_2 and F_3 of each of the five chickpea crosses *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. The seven parents involved in the crosses were selected on the basis of phenotypic diversity for yield and other attributes. The characteristics of selected parents and their pedigrees are given in Table 3.1.

3.2 CROSSING PROGRAMME AND EXPERIMENTAL DESIGN

At ARS, Durgapura the parents were crossed in *rabi* 2001-02 to obtain F_1. The F_1s were sown during the next season (*rabi*, 2002-03) to obtain F_2 generation. At the same time fresh F_1s were also made. In *rabi*, 2003-04, the respective F_1s and F_2s were raised to advance the generations to F_2 and F_3 at Agricultural Research Sub-Station, Hanumangarh. Fresh crosses were also made to get sufficient seeds of F_1 generation.

During *rabi* 2004-05, two sets of five generations (P_1, P_2, F_1, F_2 and F_3) of each family of the five crosses were evaluated in compact family block design with three replications under irrigated and rainfed (on receding soil moisture) conditions at Research Farm, Agricultural Research Sub Station, Hanumangarh. One pre-sowing irrigation and two supplemental irrigations at pre-flowering and pod development stages were given under irrigated condition. Each replication was divided in five main plots. The crosses were randomly allocated to main plots. Five generations were then randomly allocated to five sub plots within main plots. The plots for each parent consisted of two rows, F_1's consisted of one row whereas F_2's and F_3's consisted of four rows. Each row was 3 meter long and spacing between and within rows was maintained as 30 cm and 10 cm, respectively in both the conditions. Border rows were planted at the beginning as well as at the end of experimental rows in each main plot to minimize border effect. All the recommended cultural practices were followed to raise a good and healthy crop in both the conditions.

3.3 OBSERVATIONS RECORDED

The observations were recorded for eleven yield and yield related characters on randomly selected 10 plants in non-segregating (P_1, P_2, and F_1) and 20 plants in segregating generations (F_2 and F_3).

The method of recording observations during the investigation are described as under:

3.3.1 Days to 50% flowering

Days taken from sowing to flowering in 50 per cent of the plants in a plot were recorded as days to 50 % flowering.

3.3.2 Days to maturity

Days to maturity was recorded as number of days taken from sowing to the time when 75 per cent of the plants showed physiological maturity.

3.3.3 Plant height (cm)

Plant height was measured in centimeters from ground level to the tip of the longest branch at maturity in all the sampled plants and averaged.

3.3.4 Fruiting branches per plant

All pod-bearing branches were counted at the time of harvesting in all the sampled plants and averaged.

3.3.5 Pods per plant

Total number of pods were counted at the time of harvesting in all the sampled plants and averaged.

3.3.6 Seeds per pod

Seeds per pod were counted by taking average of number of seeds in 10 pods of the selected plant at the time of threshing.

3.3.7 Biological yield per plant (g)

The total above ground plant material of the randomly selected plants were weighed in grams and averaged to obtain biological yield per plant.

3.3.8 Seed yield per plant (g)

Total weight of seeds per selected plant was weighed and recorded in grams to represent seed yield per plant.

3.3.9 Harvest index (%)

Harvest index was calculated as the ratio of seed yield per plant to biological yield per plant, expressed as percentage *i.e.,*

$$\text{Harvest index (\%)} = \frac{\text{Seed yield per plant}}{\text{Biological yield per plant}} \times 100$$

3.3.10 100- seed weight (g)

100-seeds were counted at random from the harvest of each plants and weighed in gram to represent 100-seed weight.

3.3.11 Protein content (%)

Samples of seeds were taken from the harvest bulk of sampled plants and analyzed for nitrogen content after grinding. The nitrogen content was estimated by colorimetric method (Snell and Snell, 1949) using blue filter. The protein content in seed was obtained by multiplying the nitrogen content of seed by 6.25 (A.O.A.C, 1990).

3.4 STATISTICAL ANALYSES

The data were subjected to appropriate statistical analyses as under:

3.4.1 Analysis of variance

The mean values of parents, F_1s, F_2s and F_3s for all the characters were subjected to analysis of variance to make comparison among crosses as well as generations of each cross in each condition, separately as per compact family block design. The pooled analysis of variance for each cross over two environments (irrigated and rainfed) was also done according to Panse and Sukhatme (1985). The structures of ANOVA along with degrees of freedom (d f) are presented in Table 3.2, Table 3.3 and Table 3.4.

Table 3.2 ANOVA for comparison of crosses

Source of variation	d f	S S	M mean sum of squares	Expected mean sum of squares
Replications	(r-1)		M	-
Crosses	(c-1)	1		$\sigma^2_e + r\,\sigma^2_c$
Error	(r-1) (c-1)	2	M	σ^2_e
		3	M	
Total	(rc-1)			

Where,

r = Number of replications σ^2_c = Variance due to crosses

c = Number of crosses σ^2_e = Variance due to error

Table 3.3 ANOVA for comparison of generations within crosses

Source of variation	d f	S S	M mean sum of squares	Expected mean sum of squares
Replications	(r-1)		M	-
Generations	(g-1)	1		$\sigma^2_e + r\,\sigma^2_g$
Error	(r-1) (g-1)	2	M	σ^2_e
			M	

			3		
Total		(rg-1)			

Where, r, g, σ^2_g and σ^2_e represent the number of replications, number of generations in a cross, variance due to generations and variance due to error, respectively.

Table 3.4 Pooled analysis of variance for each cross

Source of variation	**d f**	**S S**	**M mean squares**	**Expected sum of**
Rep./Env.	E (r-1)		M	-
Generations (G)	(g-1)	1		$\sigma^2_e + r\ \sigma^2_{gE} + r$
Environments (E)	(E-1)		M	E σ^2_g
G x E	(g-1)	2		-
Error	(E-1)		M	$\sigma^2_e + r\ \sigma^2_{gE}$
	E (g-1)	3		σ^2_e
	(E-1)		M	
		4		
			M	
		5		
Total	(rgE-1)			

Where,

r = Number of replications in a environment

E = Number of environments

g = Number of generations in a cross

σ^2_g = Variance due to generations

σ^2_{gE} = Variance due to generation x environment interaction

σ^2_e = Variance due to error

3.4.2 Estimation of means, variances and variances of generation means

Standard statistical procedures (Snedecor and Cochran, 1968) were used to obtain means and variances for each generation and character, separately. The variance (V_X) among the individuals within each generation was estimated and

estimate of variance of generation mean ($\bar{V}_X$) was obtained by dividing the variance within generation as under:

$$\bar{V}_X = V_X/n$$

Where,

$\bar{V}_X$= Variance of generation mean

V_X= Variance among the individuals within generation

n = Number of individuals within generation

3.5 GENETICAL ANALYSES

The genetic analyses have been described under different heads as follows:

3.5.1 Scaling tests

3.5.1.1 Individual scaling test

The scales 'C' and 'D' and their variances (Mather, 1949) were calculated to test the adequacy of additive-dominance model or to determine the presence or absence of non-allelic interaction in each case using the following formulae:

Table 3.5 Individual scaling tests and their variances.

	Scale tests	**Variances**
$\bar{P}_2$	$C = 4\ \bar{F}_2 - 2\ \bar{F}_1 - \bar{P}_1 -$	$V_C = 16\ V_{\bar{F}_2} + 4\ V_{\bar{F}_1} + V_{\bar{P}_1} + V_{\bar{P}_2}$
$\bar{P}_2$	$D = 4\ \bar{F}_3 - 2\ \bar{F}_2 - \bar{P}_1 -$	$V_D = 16\ V_{\bar{F}_3} + 4\ V_{\bar{F}_2} + V_{\bar{P}_1} + V_{\bar{P}_2}$

If model is adequate the quantities 'C' and 'D' will be equal to zero individually within the limits of their standard error. The standard error for each scale is worked out by taking the square roots of the corresponding variance.

The significance of each scale was tested using 't' test,

Where,

$$t = \frac{\text{Estimate of scale}}{\text{Standard error of scale}}$$

This 't' value was compared with table 't' value at the degree of freedom of the various generations involved in the test. For each generation, the

degree of freedom (d f) is equal to the total observations (n) minus one *i.e.,* d f = n-1 (Sharma, 1998).

3.5.1.2 Joint scaling test

Joint scaling test (additive-dominance model or non-epistatic model) proposed by Cavalli (1952) was also applied to confirm the presence of interactions. It consists of estimating the parameters m, (d) and (h) using weighted least squares method, followed by a comparison of observed means with expected means. The comparison between observed and expected generation means were made by chi-square (χ^2) test assuming that the sum of squares minimized in the fitting process is distributed as χ^2. The degrees of freedom (d f) is equal to the number of generations minus the number of parameters estimated.

The procedure of weighted least square estimates of the three parameters may be illustrated as follows:

Expectations of matrix for generation means (Cavalli, 1952)

$$= \begin{vmatrix} {}_1 \\ {}_2 \\ {}_1 \\ {}_2 \\ {}_3 \end{vmatrix} \quad X= \begin{vmatrix} 1 & \\ 1 & \\ 0 & \\ 0 & /2 \\ 0 & /4 \end{vmatrix} \quad M= \begin{vmatrix} \\ d) \\ h) \end{vmatrix}$$

The equations of expectations can be expressed in a single form Y= X. M.

Where,

Y= the vectors of observed generation mean

X= the matrix of coefficient of the parameters

M= the vectors of the parameters m, (d), and (h)

The best estimates can be obtained when generation means and their expectations are weighted; the appropriate weights are the reciprocals of the variance of the mean. If 'V' denotes the error variance and covariance matrix of means, then the estimates of the parameters M are given by $M= (X^1 V^{-1} X^1)^{-1} X^1 V^{-1} Y$ and the expectation of means on three parameters model are Y= X. M.

Where,

X^1= the transpose of X

V^{-1}= the inverse of information matrix

$(X^1 V^{-1} X)^{-1}$= the weighted C-matrix.

The test of goodness of fit is χ^2 *i.e.*, χ^2 (n-p) d. f. = $\sum_{i=1}^{n} (Y_i - Y_{ii})^2 W_i$

Where,

Y_i= observed mean of i^{th} generation

Y_{ii}= expected mean of i^{th} generation

W_i =the weight of information i^{th} generation

n= number of generations

p= number of parameters estimated

The standard error of estimates of each parameters (M_i) was computed as :

SE (M_i)= $[C_{ii} \times \chi^2/(n-p)]^{1/2}$

Where,

C_{ii}= the diagonal element of the inverse matrix $(X^1 V^{-1} X)^{-1}$

χ^2= estimated value of chi-square

(n-p)= degrees of freedom for chi-square

When the three parameters or non-epistatic model was inadequate, an unweighted five-parameter model was fitted which include digenic epistatic effects. The goodness of fit of five parameters could not be tested by chi-square test since all the five generations were used for the parameter estimation.

3.5.2 Gene effects in five-parameter model

Five-parameter model (epistatic or digenic model) suggested by Hayman (1958) was used to estimate the gene effects in the presence of digenic interactions. The formulae for estimating gene effects in five-parameter model are as follows:

m= Mean= $\bar{F}_2$

(d)= Additive gene effect pooled over all loci

= 1/2($\bar{P}_1 - \bar{P}_2$)

(h)= Dominance gene effect pooled over all loci

= 1/6(4 $\bar{F}_1$ + 12 $\bar{F}_2$ – 16 $\bar{F}_3$)

(i)= Over all additive x additive epistatic gene effect

= $\bar{P}_1 - \bar{F}_2 + 1/2(\bar{P}_1 - \bar{P}_2 + h) - 1/4\ l$

(l)= Over all dominance x dominance epistatic gene effect

$=1/3\ (16\ \bar{F}_3 - 24\ \bar{F}_2 + 8\ \bar{F}_1)$

The variances have been computed using following formulae:

$V_m = V_{\bar{F}_2}$

$V_d = 1/4\ (V_{\bar{P}_1} + V_{\bar{P}_2})$

$V_h = 1/36\ (16\ V_{\bar{F}_1} + 144\ V_{\bar{F}_2} + 256\ \bar{V}_{\bar{F}_3})$

$V_i = V_{\bar{P}_1} + V_{\bar{F}_2} + 1/4\ (V_{\bar{P}_1} + \bar{V}_{\bar{P}_2} + \bar{V}_h) + 1/16\ \bar{V}_l$

$V_l = 1/9\ (256\ V_{\bar{F}_3} + 576\ V_{\bar{F}_2} + 64\ V_{\bar{F}_1})$

The standard errors of these estimates were obtained in the usual way. For example, the variance of (d) and its standard error was calculated as:

$V_d = 1/4(V_{\bar{P}_1} + V_{\bar{P}_2})$

$SE_{(d)} = [\bar{V}_d]^{1/2}$

The significance of (d) was tested by 't' test *i.e.*, t= (d)/SE (d). The standard error and 't' tests for other parameters were calculated in the similar way.

3.5.3 Heterosis and inbreeding depression

Heterosis was calculated over better parent (heterobeltiosis, as termed by Fonseca and Patterson, 1968) and mid parent for all the characters in each condition. Theoretically, heterosis is the deviation of F_1 from the mid parental values, however, in plant breeding programme, the measure of heterosis over better parent is more preferred.

(i) The heterosis over mid parent was calculated by the following formula:

Heterosis over mid parent = $\bar{F}_1 - \overline{MP}$

$$\text{Per cent heterosis over mid parent} = \frac{\bar{F}_1 - \overline{MP}}{\overline{MP}} \times 100$$

(ii) The heterosis over better parent was computed as:

Heterosis over better parent= $\bar{F}_1 - \overline{BP}$

$$\text{Per cent heterosis over better parent} = \frac{\bar{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

$\overline{BP}$

Where,

$\bar{F}_1$ = Mean value of the F_1 generation

$\overline{MP}$ = Mean value of the two parental mean values

$\overline{BP}$ = Mean value of the better parent

The significance of heterosis over mid parent and better parent were tested using 't' test as given below:

$$\text{'t'} = \frac{\bar{F}_1 - \overline{MP}}{SE\left(\bar{F}_1 - \overline{MP}\right)} \quad \text{and}$$

$$\text{'t'} = \frac{\bar{F}_1 - \overline{BP}}{SE\left(\bar{F}_1 - \overline{BP}\right)}$$

Where,

$\bar{F}_1 - \overline{MP}$ = Value of heterosis over mid parent

$\bar{F}_1 - \overline{BP}$ = Value of heterosis over better parent

$SE\left(\bar{F}_1 - \overline{MP}\right)$= Standard error of heterosis over mid parent

$SE\left(\bar{F}_1 - \overline{BP}\right)$= Standard error of heterosis over better parent

$SE\left(\bar{F}_1 - \overline{MP}\right) = \left[V_{\bar{F}_1} + 1/4\left(V_{\bar{P}_1} + V_{\bar{P}_2}\right)\right]^{1/2}$

$SE\left(\bar{F}_1 - \overline{BP}\right) = \left[V_{\bar{F}_1} + V_{\overline{BP}}\right)\right]^{1/2}$ Here, $\overline{BP} = \bar{P}_1$ or $\bar{P}_2$

Where,

$\bar{V}_{\bar{F}_1}$ = Variance of F_1 generation mean

$\bar{V}_{\bar{P}_1}$ = Variance of P_1 parental generation mean

$V_{\bar{P}_2}$ = Variance of P_2 parental generation mean

The 't' value was compared with the table 't' value at the total degree of freedom of the various generations involved in the test.

(iii) Inbreeding depression in F_2 was calculated as given below:

Inbreeding depression= $\bar{F}_1 - \bar{F}_2$

$$\text{Per cent inbreeding depression} = \frac{\bar{F}_1 - \bar{F}_2}{\bar{F}_1} \times 100$$

Where,

$\bar{F}_1$= Mean value of the F_1 generation

$\bar{F}_2$= Mean value of the F_2 generation

The significance of inbreeding depression was done as per heterosis *i.e.*, using 't' test:

$$\text{'t'} = \frac{\bar{F}_1 - \bar{F}_2}{SE\,(\bar{F}_1 - \bar{F}_2)}$$

Where,

$\bar{F}_1 - \bar{F}_2$= Value of the inbreeding depression

$SE\,(\bar{F}_1 - \bar{F}_2)$= Standard error of inbreeding depression

$SE\,(\bar{F}_1 - \bar{F}_2) = [V_{\bar{F}_1} + V_{\bar{F}_2}]^{1/2}$

Where, $V_{\bar{F}_1}$ = Variance of F_1 generation mean

$V_{\bar{F}_2}$ = Variance of F_2 generation mean

The calculated 't' value was compared with table 't' value at $n_1 + n_2 - 2$, d f.

3.5.4 Estimation of components of heterosis

Difference between the mean value of F_1 generation and that of its better parent was taken s measure of heterosis. Since the F_1 and parental generation means may be specified in terms of genetic parameters the expected magnitude of heterosis can be similarly specified. From the genetic parameters estimated in unweighted five-parameter model, components of heterosis in presence of digenic interactions were calculated using the relationship presented by Mather and Jinks (1971) as follows:

For positive heterosis,

$$\text{Heterosis (+)} = \bar{F}_1 - \bar{P}_1 = ([h] + [l]) - ([d] + [i])$$

and for negative heterosis,

$$\text{Heterosis (–)} = \bar{F}_1 - \bar{P}_2 = ([h] + [l]) - ([-d] + [i])$$

Where, P_1 corresponds to the parent with the greater mean value and P_2 to the parent with the smaller mean value, but for the present purpose, either P_1 or P_2 may be the better parent, according to the character under consideration. [d], [h], [i], and [l] are additive gene effects, dominance gene effects, additive x additive gene effects and dominance x dominance gene effects, respectively.

4. EXPERIMENTAL RESULTS

The present investigation was carried out to study “Genetics of yield and yield components in chickpea (*Cicer arietinum* L.) under irrigated and rainfed conditions”. Five generations (P_1, P_2, F_1, F_2 and F_3) of five chickpea crosses *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 were evaluated under irrigated and rainfed conditions. Observations were recorded on yield and yield contributing characters *viz*., days to 50% flowering, days to maturity, plant height (cm), fruiting branches per plant, pods per plant, seeds per pod, biological yield per plant (g), seed

yield per plant (g), harvest index (%), 100-seed weight (g) and protein content (%) for generation mean analysis. The results on inheritance of these characters were presented under the following heads:

4.1 Analysis of variance and *per se* performance

4.2 Scaling tests and gene effects

4.3 Heterosis, Inbreeding depression and components of heterosis

4.1 Analysis of variance and *per se* performance

4.1.1 Analysis of variance

Analysis of variance among crosses and generations for each character was carried out for five crosses under both the conditions The pooled analysis of variance over environments (irrigated and rainfed) was also carried out for all the characters in all the crosses The genetic analysis was carried out further only for those cases where generation mean sum squares were significant.

The analysis of variance for crosses indicated that there were significant differences among crosses for all the characters under both conditions. The generation means sums of squares were significant for all the characters in all the crosses under both the conditions, indicating significant differences among generations (Table 4.1 and 4.2).

The pooled analysis of variance over environments (irrigated and rainfed) also revealed highly significant differences among generations and environments for all the characters in all the crosses except for environments for seeds per pod in 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 was 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 for protein content in RSG-895 x RSG-888 and RSG-888 x ICC-4958. In these crosses the G x E mean variance was found non-significant and results have been described on the basis of pooled analysis over environments.

4.1.2 *Per se* performance

The *per se* performance along with their standard errors of the five generations for different characters over both the conditions have been presented in Table 4.3.1 to 4.3.11. The general mean and range of variation for each character over the environments (irrigated and rainfed) are given in Table 4.3.12. In general, mean of the F_1s exceeded that of parental mean in all the characters under both the conditions except for days to 50% flowering and protein content under rainfed and seeds per pod under both the conditions, indicating existence of heterosis. Similarly, the F_2s mean was less in comparison to F_1s in all the characters except for days to maturity under rainfed and seeds per pod under both the conditions, indicating existence of inbreeding depression. F_3s mean decreased in comparison to F_1s and F_2s and showed tendency towards their higher parent in most of the characters under both the conditions. Further, the mean of the most of the characters decreased under rainfed condition except for protein content in all the generations and for harvest index in F_1s

and F_3s (Table 4.3.13). Range for most of observed characters was relatively wider in the irrigated condition in comparison to rainfed condition. The results obtained with regards to mean performance for different characters are presented below:

4.1.2.1 Days to 50% flowering

Days to 50% flowering among the parents ranged from 65.67 (IPC-94-94) to 96.67 (BG-362) with the mean value of 89.37 under irrigated condition, whereas under rainfed it ranged from 64.00 (IPC-94-94) to 94.00 (BG-362) with the mean value of 85.13. F_1s means ranged from 87.00 (IPC-94-94 x RSG-888) to 94.67 (RSG-895 x RSG-888) with the mean value of 92.53 under irrigated condition, whereas under rainfed it ranged from 69.67 (IPC-94-94 x RSG-888) to 93.00 (BG-362 x RSG-931) with the mean value of 83.46.

The mean value of F_2s was 92.38 with a range from 87.67 (IPC-94-94 x RSG-888) to 95.33 (BG-362 x RSG-931) under irrigated condition, whereas under rainfed the mean was 83.20 with a range from 66.33 (IPC-94-94 x RSG-888) to 93.63 (BG-362 x RSG-931).In F_3s the mean value was 90.98 with a range from 88.33 (IPC-94-94 x RSG-888) to 93.63 (BG-362 x RSG-931) under irrigated condition, whereas under rainfed condition the mean value was 83.47 with a range from 67.00 (IPC-94-94 x RSG-888) to 92.67 (BG-362 x RSG-931).

Performance across both the conditions, indicated that under rainfed condition the days to 50% flowering was reduced by 4.74, 9.80, 9.94 and 8.26 per cent among the parents, F_1s, F_2s and F_3s, respectively. It is evident from the results that among the parents, IPC-94-94 was observed to be earliest to flower and imparting reasonable earliness to its cross under both the conditions.

4.1.2.2 Days to maturity

Among the parents, days to maturity varied from 109.67 (IPC-94-94) to 142.33 (ICC-4958) with the mean value of 132.66 under irrigated condition, whereas under rainfed it varied from 104.33 (IPC-94-94) to 133.33 (ICC-4958) with the mean value of 126.47.In F_1s it varied from 124.00 (IPC-94-94 x RSG-888) to 139.33 (RSG-895 x RSG-888) with the mean value of 133.80 under irrigated condition, whereas under rainfed it varied from 116.00 (IPC-94-94 x RSG-888) to 135.67 (RSG-888 x ICC-4958) with the mean value of 129.74.

In F_2s the mean value was 134.07 with a range from 125.00 (IPC-94-94 x RSG-888) to 138.67 (RSG-895 x RSG-888) under irrigated condition, whereas under rainfed the mean value was 128.01 with a range from 114.00 (IPC-94-94 x RSG-888) to 134.03 (RSG-888 x ICC-4958). The mean value of F_3s was 133.67 with a range from 127.67 (IPC-94-94 x RSG-888) to 136.33 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed the mean was 126.53 with a range from 112.00 (IPC-94-94 x RSG-888) to 133.33 (BG-362 x RSG-931).

Performance across both the conditions, indicated that under rainfed condition the days to maturity was reduced by 4.67, 3.04, 4.52 and 5.34 per cent among the parents, F_1s, F_2s and F_3s, respectively. On the basis per se performance (Table 4.3.2) and results obtained

the cross IPC-94-94 x RSG-888 was observed to be earliest to days to maturity under both the conditions.

4.1.2.3 Plant height (cm)

Plant height among the parents ranged from 42.77 (IPC-94-94) to 62.07 (ICC-4958) with the mean value of 54.24 under irrigated condition, whereas under rainfed it ranged from 41.77 (IPC-94-94) to 58.47 (BG-362) with the mean value of 49.67. In F_1s the mean value was 57.70 with a range from 48.37 (IPC-94-94 x RSG-888) to 62.20 (BG-362 x RSG-931) under irrigated condition, whereas under rainfed the mean value was 53.23 with a range from 50.20 (IPC-94-94 x RSG-888) to 55.27 (BG-362 x RSG-931).

In F_2s plant height ranged from 50.23 (IPC-94-94 x RSG-888) to 61.00 (RSG-895 x RSG-888) with the mean value of 57.47 under irrigated condition, whereas under rainfed it ranged from 48.05 (IPC-94-94 x RSG-888) to 55.18 (BG-362 x RSG-931) with the mean value of 51.86. In F_3s the mean value was 56.41 with a range from 51.23 (CSJD-901x RSG-931) to 62.93 (BG-362 x RSG-931) under irrigated condition, whereas under rainfed condition the mean value was 50.21 with a range from 43.60 (IPC-94-94 x RSG-888) to 55.15 (RSG-888 x ICC-4958).

Performance across both the conditions, indicated that under rainfed condition the plant height was reduced by 8.43, 7.74, 9.77 and 10.99 per cent among the parents, F_1s, F_2s and F_3s, respectively. Although, a decrease in plant height was observed for all the generations of each of five crosses under rainfed but BG-362 was found least affected (Table 4.3.3). BG-362 was observed to be tallest parent in both the conditions.

4.1.2.4 Fruiting branches per plant

Fruiting branches per plant among the parents ranged from 11.83 (IPC-94-94) to 16.03 (RSG-931) with the mean value of 14.02 under irrigated condition, whereas under rainfed it ranged from 8.80 (RSG-895) to 15.30 (BG-362) with the mean value of 12.42. The highest fruiting branches per plant was recorded for parent RSG-931 followed by RSG-888 under irrigated condition, whereas under rainfed highest fruiting branches per plant was recorded for BG-362 followed by ICC-4958. F_1s means ranged from17.83 (RSG-888 x ICC-4958) to 18.63 (CSJD-901x RSG-931) with the mean value of 18.36 under irrigated condition, whereas under rainfed it ranged from 11.73 (RSG-895 x RSG-888) to 16.60 (BG-362 x RSG-931) with the mean value of 14.47.

The mean value of F_2s was 16.98 with a range from 16.43 (CSJD-901x RSG-931) to 17.68 (RSG-895 x RSG-888) under irrigated condition, whereas under rainfed the mean value was 13.87 with a range from 11.28 (RSG-895 x RSG-888) to 15.37 (BG-362 x RSG-931). In F_3s the mean value was 15.65 with a range from 12.37 (IPC-94-94 x RSG-888) to 19.33 (BG-362 x RSG-931) under irrigated condition, whereas under rainfed condition the mean value was 14.95 with a range from 12.80 (CSJD-901x RSG-931) to 17.32 (BG-362 x RSG-931).

Performance across both the conditions, indicated that under rainfed condition the fruiting branches per plant was decreased by 11.38, 21.15, 18.27 and 4.44 per cent among the parents, F_1s, F_2s and F_3s, respectively. It can be inferred from Table 4.3.4 that parent BG-362 and ICC-4958 showed increased fruiting branches per plant under rainfed condition.

4.1.2.5 Pods per plant

Among the parents, pods per plant varied from 42.30 (RSG-895) to 58.93 (RSG-888) with the mean value of 53.21 under irrigated condition, whereas under rainfed it varied from 32.87 (RSG-895) to 49.80 (BG-362) with the mean value of 40.99. In F_1s it varied from 63.53 (IPC-94-94 x RSG-888) to 65.90 (CSJD-901x RSG-931) with the mean value of 65.07 under irrigated condition, whereas under rainfed it varied from 47.20 (CSJD-901x RSG-931) to 57.20 (RSG-888 x ICC-4958) with the mean value of 53.34.

In F_2s the mean was 61.83 with a range from 60.17 (IPC-94-94 x RSG-888) to 63.28 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed the mean was 52.91 with a range from 50.63 (RSG-895 x RSG-888) to 55.72 (RSG-888 x ICC-4958). The mean value of F_3s was 59.76 with a range from 44.70 (RSG-895 x RSG-888) to 69.68 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed condition the mean value was 53.94 with a range from 45.05 (RSG-895 x RSG-888) to 62.65 (RSG-888 x ICC-4958).

Performance across both the conditions, indicated that under rainfed condition the pods per plant was decreased by 22.97, 18.02, 14.43 and 9.74 per cent among the parents, F_1s, F_2s and F_3s, respectively. It can also be inferred from table 4.3.5 that a decrease in pods per plant was found for all the generation in all the crosses under rainfed condition but BG-362, IPC-94-94 and ICC-4958 were less affected. Among the parents, RSG-888 produced highest pods per plant followed by BG-362 and RSG-931 under irrigated condition, whereas under rainfed it produced by BG-362 followed by ICC-4958 and IPC-94-94.

4.1.2.6 Seeds per pod

Among the parents, seeds per pod varied from 1.30 (ICC-4958) to 1.97 (CSJD-901) with the mean value of 1.67 under irrigated condition, whereas under rainfed it varied from 1.32 (ICC-4958) to 1.80 (RSG-895) with the mean value of 1.66. In F_1s the mean was 1.65 with a range from 1.45 (RSG-888 x ICC-4958) to 1.77 (IPC-94-94 x RSG-888) under irrigated condition, whereas under rainfed the mean was 1.64 with a range from 1.55 (IPC-94-94 x RSG-888) to 1.79 (RSG-895 x RSG-888).

In F_2s seeds per pod varied from 1.47 (RSG-888 x ICC-4958) to 1.79 (CSJD-901x RSG-931) with the mean value of 1.66 under irrigated condition, whereas under rainfed it varied from 1.55 (RSG-888 x ICC-4958) to 1.75 (RSG-895 x RSG-888) with the mean value of 1.66. In F_3s the mean was 1.55 with a range from 1.28 (RSG-888 x ICC-4958) to 1.88 (IPC-94-94 x RSG-888) under irrigated condition, whereas under rainfed the mean was 1.54 with a range from 1.36 (RSG-888 x ICC-4958) to 1.78 (IPC-94-94 x RSG-888).

Performance across both the conditions, indicated that under rainfed condition the seeds per pod was reduced by 0.95, 0.63, 0.44 and 0.42 per cent among the parents, F_1s,

F_2s and F_3s, respectively. These minute reduction in mean values indicated that seeds per pod was not significantly affected by moisture stress.

4.1.2.7 Biological yield per plant (g)

Among the parents, biological yield per plant ranged from 34.51 (CSJD-901) to 44.99 (ICC-4958) with the mean value of 38.02 under irrigated condition, whereas under rainfed it ranged from 29.09 (CSJD-901) to 38.35 (BG-362) with the mean value of 32.99. The highest biological yield per plant was observed for parent ICC-4958 followed by RSG-888 under irrigated, whereas under rainfed condition it was observed for BG-362 followed by RSG-895 and ICC-4958. In F_1s the mean was 44.86 with a range from 42.38 (CSJD-901x RSG-931) to 50.56 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed the mean was 38.27 with a range from 32.49 (CSJD-901x RSG-931) to 41.61 (RSG-888 x ICC-4958).

In F_2s biological yield per plant varied from 38.11 (CSJD-901x RSG-931) to 48.32 (RSG-888 x ICC-4958) with the mean value of 43.05 under irrigated condition, whereas under rainfed it varied from 35.52 (CSJD-901x RSG-931) to 39.29 (RSG-888 x ICC-4958) with the mean value of 36.92. In F_3s the mean was 40.13 with a range from 34.52 (RSG-895 x RSG-888) to 47.61 (BG-362 x RSG-931) under irrigated condition, whereas under rainfed the mean was 36.44 with a range from 28.43 (CSJD-901x RSG-931) to 42.91 (BG-362 x RSG-931).

Performance across both the conditions, indicated that under rainfed condition the biological yield per plant was decreased by 13.23, 14.69, 14.26 and 9.19 per cent among the parents, F_1s, F_2s and F_3s, respectively.

4.1.2.8 Seed yield per plant (g)

Seed yield per plant among the parents varied from 13.93 (CSJD-901) to 17.98 (RSG-888) with the mean value of 16.01 under irrigated condition, whereas under rainfed it varied from 11.01 (CSJD-901) to 16.38 (IPC-94-94) with the mean value of 13.44. The highest seed yield per plant was observed for RSG-888 followed by RSG-931 under irrigated condition and under rainfed highest yield per plant was observed for IPC-94-94 followed by ICC-4958 and BG-362. In F_1s the mean value was 20.45 with a range from 18.50 (CSJD-901x RSG-931) to 22.44 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed the mean value was 17.87 with a range from 13.76 (CSJD-901x RSG-931) to 20.89 (RSG-888 x ICC-4958).

The mean value of F_2s was 18.71 with a range from 15.09 (CSJD-901x RSG-931) to 20.73 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed condition the mean value was 16.57 with a range from 14.23 (CSJD-901x RSG-931) to 19.19 (RSG-888 x ICC-4958). In F_3s the mean value was 18.94 with a range from 13.95 (CSJD-901x RSG-931) to 22.43 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed the mean value was 16.63 with a range from 10.98 (RSG-895 x RSG-888) to 21.49 (RSG-888 x ICC-4958).

Performance across both the conditions, indicated that under rainfed condition seed yield per plant was reduced by 16.01, 12.62, 11.41 and 12.21 per cent among the parents, F_1s, F_2s and F_3s, respectively.

4.1.2.9 Harvest index (%)

Among the parents, harvest index ranged from 38.96 (ICC-4958) to 45.29 (RSG-888) with the mean value of 41.92 under irrigated condition, whereas under rainfed it ranged from 34.33 (RSG-888) to 47.56 (IPC-94-94) with the mean value of 41.30. The highest value of harvest index was recorded for parent RSG-888 followed by RSG-931 under irrigated, whereas under rainfed condition highest harvest index was recorded for IPC-94-94 followed by ICC-4958 and BG-362. Among the parents, IPC-94-94, ICC-4958 and BG-362 showed increased harvest index under rainfed as compared to irrigated condition. In F_1s the mean value was 47.96 with a range from 45.82 (CSJD-901x RSG-931) to 49.25 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed the mean was 48.76 with a range from 42.35 (CSJD-901x RSG-931) to 52.74 (RSG-888 x ICC-4958).

The mean value of F_2s was 46.33 with a range from 44.24 (CSJD-901x RSG-931) to 47.85 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed condition the mean value was 46.31 with a range from 40.06 (CSJD-901x RSG-931) to 50.12 (RSG-888 x ICC-4958). In F_3s the mean was 46.80 with a range from 40.61 (CSJD-901 x RSG-931) to 52.50 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed the mean was 47.39 with a range from 37.33 (RSG-895 x RSG-888) to 53.04 (RSG-888 x ICC-4958).

Performance across both the conditions, indicated that under rainfed condition the harvest index was reduced by 1.48, -1.66, 0.04 and -1.26 per cent among the parents, F_1s, F_2s and F_3s, respectively. The negative sign in F_1s and F_3s values indicated that there was increase in the mean values of harvest index under rainfed condition.

4.1.2.10 100-seed weight (g)

100-seed weight among the parents varied from 15.41 (RSG-931) to 28.72 (ICC-4958) with the mean value of 19.10 under irrigated condition, whereas under rainfed it varied from 14.38 (CSJD-901) to 27.19 (ICC-4958) with the mean value of 18.34. In F_1s the mean was 21.82 with a range from 17.20 (RSG-895 x RSG-888) to 26.25 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed the mean was 20.92 with a range from 16.68 (CSJD-901x RSG-931) to 24.13 (RSG-888 x ICC-4958).

The mean value of F_2s was 21.28 with a range from 17.00 (RSG-895 x RSG-888) to 25.46 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed condition the mean value was 20.55 with a range from 16.48 (CSJD-901x RSG-931) to 23.93 (RSG-888 x ICC-4958). In F_3s the mean was 22.07 with a range from 17.80 (CSJD-901 x RSG-931) to 26.48 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed the mean was 20.92 with a range from 17.43 (CSJD-901x RSG-931) to 24.86 (BG-362 x RSG-931).

Performance across both the conditions, indicated that under rainfed condition 100-seed weight was decreased by 3.98, 4.11, 3.39 and 5.24 per cent among the parents, F_1s,

F_2s and F_3s, respectively. Among the parents, ICC-4958 exhibited highest 100-seed weight followed by IPC-94-94 and BG-362 under both the conditions.

4.1.2.11 Protein content (%)

Among the parents, protein content ranged from 17.13 (RSG-888) to 20.63 (IPC-94-94) with the mean value of 18.45 under irrigated condition, whereas under rainfed it ranged from 17.22 (RSG-895) to 20.69 (IPC-94-94) with the mean value of 18.82. In F_1s the mean was 18.59 with a range from 17.58 (RSG-895 x RSG-888) to 19.38 (RSG-888 x ICC-4958) under irrigated condition, whereas under rainfed the mean was 18.71 with a range from 18.19 (RSG-895 x RSG-888) to 19.17 (BG-362 x RSG-931).

The mean value of F_2s was 18.15 with a range from 17.29 (RSG-895 x RSG-888) to 18.63 (BG-362 x RSG-931) under irrigated condition, whereas under rainfed condition the mean value was 18.56 with a range from 17.99 (RSG-895 x RSG-888) to 19.25 (BG-362 x RSG-931). In F_3s protein content varied from 16.99 (RSG-895 x RSG-888) to 18.63 (CSJD-901x RSG-931) with the mean value of 17.95 under irrigated condition, whereas under rainfed it varied from 17.60 (RSG-895 x RSG-888) to 18.93 (BG-362 x RSG-931) with the mean value of 18.51.

Performance across both the conditions, indicated that under rainfed condition protein content was decreased by -2.05, -0.65, -2.29 and -3.12 per cent among the parents, F_1s, F_2s and F_3s, respectively. The minus (-) indicating a meager increase protein content under rainfed in comparison to irrigated condition.

4.2 Scaling tests and gene effects

Generation means and their standard errors with respect to different characters in five crosses evaluated under irrigated and rainfed conditions were first subjected to individual scaling test ‘C’ and ‘D’. The results of individual scaling test were further confirmed by joint scaling test (Cavalli, 1952), which effectively combined the whole set of scaling tests and thus after a more convenient, adaptable and informative approach for testing adequacy of simple additive-dominance model (3-parameter model) when, it did not fit, the 5-parameter model as described by Hayman (1958) was applied. The relative magnitude of different gene effects (expressed as percentage of mid parent value) are presented in Table 4.4.1 to 4.4.11 and the inferences made there of are described as under:

4.2.1 Days to 50% flowering

RSG-895 x RSG-888

Individual scaling tests revealed significant value of scale ‘D’ in irrigated and scale ‘C’ in both irrigated and rainfed conditions, which indicated the presence of epistasis in both the conditions. The joint scaling test also provided evidence for failure of additive-dominance model in both the conditions (Table 4.4.1). In five-parameter model, additive (d) and dominance (h) gene effects were found to be significant under both irrigated and rainfed

conditions. Among epistatic interactions, additive x additive (i) was significant in rainfed and dominance x dominance (l) was significant in both the conditions. The relative magnitude of gene effects indicated that (l) followed by (h) under irrigated and (l) followed by (i) and (h) under rainfed condition contributed maximum to the inheritance of character. The opposite signs and significant values of (h) and (l) indicated the presence of duplicate type of epistasis in this cross under both the conditions.

RSG- 888 x ICC-4958

In this cross also 3-parameter model was observed to be inadequate under both the conditions, since under irrigated condition scale 'D' and under rainfed condition both 'C' and 'D' scales were found to be significant indicating the presence of epistasis. The joint scaling test also revealed presence of epistatic interaction under both the conditions (Table 4.4.1). Main effects additive (d) and dominance (h) as well as interaction effects additive x additive (i) and dominance x dominance (l) exhibited significant values in both the conditions. Among the significant parameters (l) followed by (h) in irrigated and (l) followed by (i) in rainfed condition contributed maximum to govern the trait. The opposite signs of significant parameters (h) and (l), indicated the presence of duplicate type of epistasis in both the conditions.

IPC-94-94 x RSG- 888

Individual as well as joint scaling tests were found significant under both irrigated and rainfed conditions indicated the presence of non-allelic interactions (Table 4.4.1). Additive effect (d) and additive x additive (i) interaction effect were significant under both the conditions whereas dominance (h) and dominance x dominance (l) effects were significant under irrigated and rainfed condition, respectively. The relative magnitude of gene effects revealed that (i) followed by (d) in irrigated and (i) followed by (l) in rainfed condition contributed maximum to the inheritance of character. No conclusion could be drawn regarding epistasis under both the conditions.

CSJD-901 x RSG- 931

The significance of individual and joint scaling tests indicated the presence of non-allelic interactions in both the conditions (Table 4.4.1). The gene effects *viz.,* additive (d), dominance (h) and dominance x dominance (l) were significant in both the conditions whereas, additive x additive (i) was significant in rainfed only. Among significant parameters, (l) followed by (h) contributed maximum to create variation among generation means under both the conditions. The significant values and opposite signs of (h) and (l), indicated the presence of duplicate type of epistasis in this cross in both the conditions.

BG-362 x RSG- 931

Individual as well as joint scaling tests indicated the presence of epistatic interactions in both the conditions (Table 4.4.1). All the gene effects viz., additive (d), dominance (h), additive x additive (i) and dominance x dominance (l) were significant under both the conditions. Among significant parameters, (l) followed by (i) contributed maximum to the inheritance of trait

under both the conditions .The opposite signs of significant parameters (h) and (l), indicated the presence of duplicate type of epistasis in this cross in both the conditions.

4.2.2 Days to maturity

RSG-895 x RSG-888

The scales 'C' and 'D' were found significant under irrigated condition whereas scale 'C' was significant under rainfed, indicated the presence of epistasis. Joint scaling test further confirmed the failure of additive-dominance model under both the conditions (Table 4.4.2). In five parameter model, additive effect (d), dominance (h) and dominance x dominance (l) gene effects were found significant under both the conditions whereas, additive x additive (i) gene effect was found significant only under irrigated condition. The significant parameter (l) followed by (h) and (i) contributed maximum to the inheritance of character in irrigated and (l) followed by (h) in rainfed condition. Significant values and opposite signs of (h) and (l), indicated the presence of duplicate type of epistasis in this cross in both the conditions.

RSG-888 x ICC-4958

The significant values of scale 'D' and χ^2-test (joint scaling) indicated the presence of epistasis under both the conditions (Table 4.4.2). The gene effects additive (d), dominance (h), additive x additive (i) and dominance x dominance (l) were found significant under both the conditions. Among the significant parameters, (l) in irrigated and (d) followed by (l) in rainfed condition played maximum role in the inheritance of the character. The significant values and opposite signs of (h) and (l), indicated the presence of duplicate type of epistasis in this cross in both the conditions.

IPC-94-94 x RSG-888

The scales 'C' and 'D' as well as joint scaling test were found significant under both the conditions indicating the inadequacy of additive-dominance model (Table 4.4.2). The gene effects additive (d), dominance (h), additive x additive (i) and dominance x dominance (l) in irrigated condition and additive (d), dominance (h) and additive x additive (i) were found significant in rainfed condition. Among the significant parameters, (i) followed by (d) contributed maximum to the inheritance of the character under both the conditions. The (h) and (l) parameters were significant and had opposite signs, thus, duplicate type of epistasis was present under irrigated condition and no conclusion could be drawn regarding epistasis under rainfed condition.

CSJD-901 x RSG-931

Results of scaling tests revealed that scale 'C' was significant under both the conditions indicated the role of epistatic interactions. Significant χ^2-values of joint scaling test further suggested the inadequacy of additive-dominance model and it was considered appropriate to use five-parameter model for the estimation of gene effects under both the conditions (Table 4.4.2). The main effects additive (d) and dominance (h) and their interaction effects *i.e.,* additive x additive (i) and dominance x dominance (l) were found significant under both the conditions. The relative magnitude of significant gene effects, indicated that parameter (l) in irrigated and (h) in rainfed

condition contributed more to the inheritance of character. Duplicate type of epistasis was observed in both the conditions as the estimates (h) and (l) were significant and had opposite signs.

BG-362 x RSG-931

The scale 'C' was significant in rainfed, while scale 'D' was significant in both irrigated and rainfed conditions, indicated the role of epistatic interactions. Significant χ^2-values of joint scaling test further supported the inadequacy of additive-dominance model in both the conditions (Table 4.4.2). In five parameter model, the gene effects *viz.,* additive (d), dominance (h), additive x additive (i) and dominance x dominance (l) were found significant in both the conditions. The significant parameters (l) followed by (i) contributed maximum to the inheritance of character under both the conditions. In both the conditions significant values and opposite signs of (h) and (l), indicated the duplicate type of epistasis.

4.2.3 Plant height (cm)

RSG-895 x RSG-888

The scale 'D' as well as joint scaling test were significant under both the conditions, indicating inadequacy of additive-dominance model (Table 4.4.3). Therefore, five parameter model was used to study gene effects under both irrigated and rainfed conditions. The main effects additive (d) and dominance (h) and dominance x dominance (l) interaction effect were significant under both the conditions and additive x additive (i) interaction effect was significant only under irrigated condition. Among the significant parameters, (l) followed by (h) in both the conditions contributed more to govern this trait. The opposite signs and significant values of (h) and (l), indicated the duplicate type of epistasis under both the conditions.

RSG-888 x ICC-4958

In this cross also scale test 'D' and joint scaling test were found significant under both the conditions (Table 4.4.3). As a matter of fact, 5-parameter model was used to estimate gene effects and their interactions under both the conditions. The main effects additive (d) and dominance (h) and additive x additive (i) interaction effect were found significant under both the conditions, whereas dominance x dominance (l) effect was found significant only in rainfed condition. The parameter (i) in irrigated and (l) followed by (i) in rainfed condition contributed more to the inheritance of character. The opposite signs and significant values of (h) and (l), indicated the presence of duplicate type of epistasis only in rainfed condition.

IPC-94-94 x RSG-888

Individual scaling tests as well as joint scaling test revealed the presence of epistasis under both the conditions as a matter of fact five parameter model was used to estimate gene effects and their interactions under both the conditions (Table 4.4.3). The main effects additive (d) and dominance (h) were significant under both irrigated and rainfed conditions and among interaction effects additive x additive (i) in irrigated and dominance x dominance (l) in rainfed were found significant. The parameters, (i) in irrigated and (l) followed by (h) in rainfed condition contributed maximum to the inheritance of trait. Significant values and opposite signs of (h) and (l), indicated the presence of duplicate type of epistasis in rainfed condition only.

CSJD-901 x RSG-931

The significant values of scale 'D' and joint scaling test indicated the inadequacy of additive-dominance model under both the conditions (Table 4.4.3). Therefore, 5-parameter model was used to estimate the gene effects and their interactions under both the conditions. The gene effects additive (d) and dominance (h) and dominance x dominance (l) interaction effect were found significant in irrigated condition and only additive x additive (i) interaction effect was found significant in rainfed condition. The relative magnitude of significant parameters revealed that (l) followed by (h) in irrigated and (l) in rainfed condition played maximum role in the inheritance of character. Significant values and opposite signs of (h) and (l), indicated duplicate type of epistasis in irrigated condition.

BG-362 x RSG-931

Scale 'D' was significant in both irrigated and rainfed conditions, which indicated the role of epistatic interactions. Significant χ^2- values of joint scaling test further supported the inadequacy of 3-parameter model in both the conditions (Table 4.4.3). Therefore, five-parameter model was used to estimate the gene effects and their interactions under both the conditions. The main effects additive (d) and dominance (h) and interaction effects additive x additive (i) and dominance x dominance (l) were found significant under both the conditions. Among significant parameters, (l) followed by (i) and (h) contributed maximum to the mean performance of character under both the conditions. The opposite signs and significant values of (h) and (l), indicated duplicate type of epistasis under both the conditions.

4.2.4 Fruiting branches per plant

RSG-895 x RSG-888

Under irrigated condition scale 'C' and under rainfed condition scale 'D' was found significant, indicating the presence of epistasis. The joint scaling test also confirmed the presence of epistasis under both the conditions (Table 4.4.4). Therefore, digenic interaction model (5-parameter model) was used to estimate the gene effects and interaction effects under both the conditions. The gene effects *viz.,* additive (d), dominance (h) and dominance x dominance (l) were found significant under both the conditions, whereas additive x additive (i) was significant under rainfed condition only. Among significant parameters, (l) followed by (h) in irrigated and (l) followed by (i) in rainfed condition contributed maximum to the inheritance of character. The opposite signs and significant values of (h) and (l), indicated duplicate type of epistasis under both the conditions for this cross.

RSG-888 x ICC-4958

Individual scaling test 'D' was significant under both the conditions. The χ^2-values were also in agreement with individual scaling test and indicated the role of non-allelic interactions (Table 4.4.4). Main effects additive (d) and dominance (h) and their interactions additive x additive (i) and dominance x dominance (l) were significant in both the conditions. The parameter (l) followed by (i) and (h) contributed maximum to govern the trait under both the conditions. The significant values and opposite signs of (h) and (l), indicated the presence of duplicate type of epistasis in both the conditions.

IPC-94-94 x RSG-888

The individual scaling test ‘D’ was found significant in both irrigated and rainfed conditions, indicating the presence of epistasis. The χ^2-values were also significant under both the conditions, which confirmed the inadequacy of additive-dominance model (Table 4.4.4). In the five parameter model, the gene effects additive (d), dominance (h), additive x additive (i) and dominance x dominance (l) were found significant under both the conditions. The relative magnitude of significant parameters revealed that (l) followed by (h) in irrigated and (l) followed by (i) in rainfed condition contributed maximum to the inheritance of character. The opposite signs and significant values of (h) and (l), indicated the duplicate type of epistasis in both the conditions for this cross.

CSJD-901 x RSG-931

The individual scaling tests ‘C’ in rainfed and ‘D’ in both irrigated and rainfed conditions were found significant, indicating the presence of epistasis in both the conditions. Significant value of joint scaling test also confirmed the inadequacy of additive-dominance model in both the conditions (Table 4.4.4). Therefore, five-parameter model was applied to estimate the gene effects and interactions under both the conditions. The results revealed that additive (d) and dominance (h) effects were significant in irrigated condition and additive (d), dominance (h) along with dominance x dominance (l) were found significant in rainfed condition. Among significant parameters, (h) in irrigated and (l) followed by (h) in rainfed condition played maximum role in the inheritance of this trait. The significant values and opposite signs of (h) and (l), indicated duplicate type of epistasis in rainfed condition only.

BG-362 x RSG-931

Individual scaling test ‘D’ was found significant in both irrigated and rainfed conditions. The χ^2-values were also in agreement with individual scaling tests and indicated the role of non-allelic interactions in both the conditions (Table 4.4.4). Main effects additive (d) and dominance (h) and their interactions additive x additive (i) and dominance x dominance (l) were significant in both the conditions except additive (d) in rainfed condition. The relative magnitude of significant parameters indicated that (l) followed by (i) and (h) contributed maximum to the inheritance of character under both the conditions. The significant values and opposite signs of (h) and (l), indicated the presence of duplicate type of epistasis in both the conditions.

4.2.5 Pods per plant

RSG-895 x RSG-888

The individual scaling tests indicated that scales 'C and 'D' were significant under rainfed and irrigated conditions, respectively, indicated the presence of epistasis under both the conditions (Table 4.4.5). The significant χ^2-values of joint scaling test also confirmed the presence of epistasis under both the conditions. Therefore, five parameter model was used to estimate gene effects and their interactions under both the conditions. Additive effect (d), dominance effect (h) and dominance x dominance (l) interaction were significant under both the conditions, whereas additive x additive (i) interaction was significant only under irrigated condition. The parameters (l) followed by (d) in irrigated and (l) in rainfed condition contributed maximum to the inheritance of character. The opposite signs and significant values of (h) and (l), indicated the presence of duplicate type of epistasis under both the conditions.

RSG-888 x ICC-4958

Results of individual scaling test showed that scale 'C' was significant under rainfed condition, whereas scale 'D' was found significant under both irrigated and rainfed conditions, indicated the presence of epistasis(Table 4.4.5). The significant χ^2-values of joint scaling tests also confirmed the presence of epistasis under both the conditions. In five parameter model, additive (d) and dominance (h) and additive x additive (i) and domonance x dominance (l) gene effects were found significant under both the conditions. Among significant parameters, (l) in irrigated and (i) followed by (l) in rainfed condition contributed more to the inheritance of the character. The significant values and opposite signs of (h) and (l), indicated the presence of duplicate type of epistasis in both the conditions.

IPC-94-94 x RSG-888

The scale 'D' was significant under both the conditions indicated the presence of epistasis. The joint scaling tests were also confirmed inadequacy of additive-dominance model in both the conditions (Table 4.4.5). Thus, according to results five-parameter model was fitted to study the gene effects and their interactions under both the conditions. Additive effect (d), additive x additive (i) and dominance x dominance (l) gene effects were significant under both the conditions, whereas dominance effect (h) was significant only under irrigated condition. Among the significant parameters, (l) followed by (i) contributed more to creation of variation in generation means under both the conditions. The significant values and opposite signs of (h) and (l), indicated the presence of duplicate type of epistasis in irrigated condition, whereas under rainfed condition no conclusion could be drawn regarding type of epistasis as (h) parameter was non-significant.

CSJD-901 x RSG-931

In this cross scale 'C' and 'D' were found significant under rainfed and irrigated conditions, respectively. The joint scaling test was also significant under both the conditions, confirmed the presence of epistasis (Table 4.4.5) Thus, Five-parameter model was fitted to study the gene effects and their interactions. Additive (d), dominance (h) and dominance x dominance (l) gene effects were significant under both the conditions, whereas additive x additive (i) interaction was significant only under irrigated condition. The significant

parameters (l) and (h) contributed maximum to the inheritance of character under both the conditions. The significant values and opposite signs of (h) and (l), indicated the duplicate type of epistasis under both the conditions.

BG-362 x RSG-931

Individual scaling test as well as joint scaling test indicated the role of non-allelic interactions to account genetic variation in both the conditions (Table 4.4.5). The main effects additive (d) and dominance (h) and their interactions *i.e.,* additive x additive (i) and dominance x dominance (l) were found significant in both the conditions. The relative magnitude of significant parameters revealed that (l) followed by (i) and (h) contributed maximum to the inheritance of character under both the conditions. Duplicate type of gene interaction was observed in both the conditions as the estimates of (h) and (l) were significant and had opposite signs.

4.2.6 Seeds per pod

RSG-895 x RSG-888

Since the G x E variance was found to be non-significant in this cross, so the results have been described on the basis of pooled data over environments (irrigated and rainfed). In this cross individual scaling test 'D' was significant. The significant values of χ^2 of joint scaling test provided evidence for the presence of non-allelic interactions (Table 4.4.6). Among the components of five parameter model, dominance (h), additive x additive (i) and dominance x dominance (l) were observed significant. The parameter (l) followed by (i) and (h) had maximum influence in the inheritance of the trait in this cross. The results indicated the duplicate type of epistasis in this cross.

RSG-888 x ICC-4958

In this cross also G x E variance was found non-significant therefore, the results have been described on the basis of pooled data over environments (irrigated and rainfed). Individual scaling test 'D' as well as joint scaling test indicated the presence of non-allelic interactions in this cross (Table 4.4.6). All the estimated components of five-parameter model were found significant. The parameter (l) followed by (i) and (h) contributed more to the inheritance of this trait. The significant values and opposite signs of (h) and (l), indicated the presence of duplicate type of epistasis in this cross.

IPC-94-94 x RSG-888

Individual scaling test 'D' was significant in both irrigated and rainfed conditions. The significance of χ^2-value of joint scaling test further supported the presence of epistatic interactions in both the conditions (Table 4.4.6). Among the components of five-parameter model, additive (d) in rainfed and additive x additive (i) in both irrigated and rainfed were found significant, thus (d) in rainfed and (i) in both conditions contributed towards genetic variation. No conclusion could be drawn regarding type of epistasis under both the conditions as parameters (h) and (l) were non significant.

CSJD-901 x RSG-931

The significance of individual scaling test 'D' as well as joint scaling test indicated the presence of non-allelic interactions in both the conditions (Table 4.4.6). Among the components of five-parameter model, dominance (h) and additive x additive (i) were significant under both the conditions, whereas

additive (d) was found significant only in irrigated condition. The significant parameter (i) followed by (h) had maximum influence in the inheritance of this trait under both the conditions. No conclusion could be drawn regarding type of epistasis in both the conditions, since, parameter (l) was non significant.

BG-362 x RSG-931

Individual scaling test 'D' was significant in pooled analysis over the environments. The significance of χ^2-values of joint scaling test was also revealed in adequacy of additive-dominance model (Table 4.4.6). Therefore, five-parameter model was fitted to estimate the gene effects and their interactions in pooled analysis. Among the gene effects, dominance (h) and among the interactions, additive x additive (i) were found significant. Both of these significant parameters thus contributed towards genetic variation in this cross. Since (l) was non-significant thus,no conclusion could be drawn about the type of epistasis in this cross.

4.2.7 Biological yield per plant

RSG-895 x RSG-888

The significance of individual scaling test 'D' as well as joint scaling test revealed the presence of non-allelic interactions in both the conditions (Table 4.4.7). The main effects additive (d), dominance (h) and interaction effects additive x additive (i) and dominance x dominance (l) were found significant under both the conditions. Among the significant parameters, (l) followed by (h) had maximum influence in the inheritance of character. The opposite signs and significant values of (h) and (l), indicated the presence of duplicate type of epistasis in both conditions.

RSG-888 x ICC-4958

Individual scaling tests revealed significant values of 'D' in both the conditions. Joint scaling test further confirmed the failure of additive-dominance model in both irrigated and rainfed conditions (Table 4.4.7). In five-parameter model both main effects and dominance x dominance (l) interaction effect were found significant in both the conditions, whereas additive x additive (i) was found significant only in rainfed. The significant parameters (l) followed by (h) in irrigated and (l) followed by (i) in rainfed condition contributed maximum to the inheritance of trait. Significant values and opposite signs of (h) and (l), indicated the presence of duplicate type of epistasis in both the conditions.

IPC-94-94 x RSG-888

In this cross also individual scaling tests as well as joint scaling test revealed the presence of epistasis for both the conditions (Table 4.4.7). The gene effects *viz.,* additive (d), additive x additive (i) and dominance x dominance (l) were significant in both the conditions, whereas dominance effect (h) was significant in irrigated condition only. The parameter (l) followed by (h) in irrigated and (l) followed by (i) in rainfed condition contributed maximum to the genetic variation. Parameters (h) and (l) had significant values and opposite signs, indicating the presence of duplicate type of epistasis in irrigated condition.

CSJD-901 x RSG-931

Scale 'D' was significant in both irrigated and rainfed conditions, which indicated the role of epistatic interactions. Significant χ^2-values of joint scaling test further supported the inadequacy of 3-parameter model in both the conditions (Table 4.4.7). In 5-parameter model, additive (d), additive x additive (i) and dominance x dominance (l) were significant in both the conditions, while dominance (h) components was significant in rainfed only. The relative magnitude of significant parameters indicated that (l) followed by (i) in irrigated condition and (l) followed by (h) in rainfed condition had maximum influence on the inheritance of trait. The significant values and opposite signs of (h) and (l), indicated duplicate type of epistasis in rainfed condition.

BG-362 x RSG-931

The scale 'C in irrigated and scale 'D' in both irrigated and rainfed conditions were found significant which indicated the role of epistatic interactions. It was further confirmed by χ^2-values under joint scaling test (Table 4.4.7). Therefore, five-parameter model was fitted to estimate the gene effects and their interactions. In five parameter model additive (d), dominance (h) and additive x additive (i) components under both irrigated and rainfed conditions and dominance x dominance (l) under rainfed were found significant. Among the significant parameters, (i) in irrigated and (l) in rainfed had maximum contribution in the inheritance of trait. The significant values and opposite signs of (h) and (l), indicated the duplicate type of epistasis in rainfed condition.

4.2.8 Seed yield per plant (g)

RSG-895 x RSG-888

The significance of individual scaling test 'D' and χ^2-values of joint scaling test indicated the presence of epistasis in both irrigated and rainfed conditions (Table 4.4.8). Therefore, digenic interactions model (5-parameter model) was used to estimate gene effects and their interactions. Additive (d), additive x additive (i) and dominance x dominance (l) gene effects under both the conditions and dominance effect (h) in rainfed were found significant. Among the significant parameters, (l) followed by (i) in irrigated and (l) followed by (h) in rainfed condition contributed maximum to the genetic variation in this cross. The significant values and opposite signs of (h) and (l), indicated duplicate type of epistasis in rainfed condition.

RSG-888 x ICC-4958

Individual as well as joint scaling tests indicated the inadequacy of additive-dominance model in both irrigated and rainfed conditions (Table 4.4.8). The main effect additive (d) and interaction effects additive x additive (i) and dominance x dominance (l) in both the conditions and dominance effect (h) in rainfed were found significant. Among the significant parameters, (l) followed by (i) contributed more to the inheritance of the character under both the conditions. The significant values and opposite signs of (h) and (l), indicated duplicate type of epistasis in this cross in rainfed condition.

IPC-94-94 x RSG-888

Similar to previous cross, additive-dominance model was inadequate in both the conditions for this cross (Table 4.4.8). In five-parameter model additive effect (d), dominance effect (h) and dominance x dominance (l) interaction were found significant under both the conditions and additive x

additive (i) interaction in rainfed was found significant. The significant (l) followed by (h) in irrigated and (l) followed by (i) in rainfed condition had maximum influence on the mean performance of the trait. The significant values and opposite signs of (h) and (l), indicated the duplicate type of epistasis in this cross in both the conditions.

CSJD-901 x RSG-931

In individual scaling test scale 'C' was significant under both the conditions, whereas only scale 'D' was significant under rainfed, indicated the presence of epistasis in both the conditions. The significance of χ^2-values of joint scaling test further supported the presence of epistatic interactions in both the conditions (Table 4.4.8). The main effects additive (d) and dominance (h) under both the conditions and interaction effects additive x additive (i) and dominance x dominance (l) in rainfed condition were found significant. The parameter (h) in irrigated and (l) followed by (h) in rainfed condition had maximum influence on the inheritance of the trait. The significant values and opposite signs of (h) and (l), indicated the duplicate type of epistasis in rainfed condition.

BG-362 x RSG-931

Individual scaling test 'D' was significant in both the conditions, whereas only 'C' was significant in irrigated. The joint scaling tests also revealed presence of epistatic interactions in both the conditions in this cross (Table 4.4.8). Both the main effects additive (d) and dominance (h) and their interaction effects additive x additive (i) and dominance x dominance (l) exhibited significant values in both the conditions. Among the significant parameters, (l) and (i) had maximum influence on the inheritance of the character under both the conditions. The significant values and opposite signs of (h) and (l), indicated duplicate type of epistasis in both the conditions.

4.2.9 Harvest index (%)

RSG-895 x RSG-888

The scale test 'D' was significant under both irrigated and rainfed conditions. The significant χ^2-values of joint scaling test provided evidence for the presence of epistatic interactions in both the conditions (Table 4.4.9). The main effects additive (d) and dominance (h) and interaction effect dominance x dominance (l) only under both the conditions and additive x additive (i) under irrigated condition were found significant. The relative magnitude of significant parameters indicated that parameter (l) followed by (i) in irrigated and (l) followed by (h) in rainfed condition had maximum influence on the inheritance of the trait. The opposite signs and significant values of (h) and (l), indicated the presence of duplicate type of epistasis in both the conditions.

RSG-888 x ICC-4958

Scale ‘D’ as well as χ^2-values of joint scaling test were significant under both the conditions indicated the presence of epistatic interactions under both irrigated and rainfed conditions (Table 4.4.9). Therefore, 5-parameter model was fitted to estimate gene effects and their interactions. Additive (d) and additive x additive (i) gene effects were significant under both the conditions. Dominance (h) and dominance x dominance (l) interaction effects were significant under irrigated and rainfed condition, respectively. Among the significant parameters, (i) in irrigated and (l) followed by (i) in rainfed contributed maximum to the inheritance of the trait. No conclusion could be drawn regarding type of epistasis under both the conditions as (l) and (h) were non-significant under irrigated and rainfed condition, respectively.

IPC-94-94 x RSG-888

In this cross individual scaling test as well as joint scaling test indicated the role of epistatic interactions under both the conditions (Table 4.4.9). The main effects additive (d) and dominance (h) and interaction effects additive x additive (i) and dominance x dominance (l) were found significant in five parameter model under both the conditions. The significant parameter (l) followed by (h) in irrigated and (l) followed by (i) in rainfed condition had maximum influence on the mean performance of the character. The parameter (h) and (l) were significant and had opposite signs thus duplicate epistasis was present under both irrigated and rainfed conditions.

CSJD-901 x RSG-931

Scaling test ‘D’ was significant under both irrigated and rainfed conditions. Significant χ^2-values of joint scaling test under both the conditions also revealed inadequacy of 3-parameter model (Table 4.4.9). Dominance gene effect (h) and dominance x dominance (l) interaction effect were significant under both the conditions and additive (d) and additive x additive (i) effects only under rainfed condition were found significant. The significant parameter (i) in irrigated and (l) in rainfed condition contributed maximum to the genetic variation. Duplicate type of gene action was recorded in both the conditions, since both (h) and (l) had significant values and opposite signs.

BG-362 x RSG-931

Individual scaling test ‘D’ in both the conditions and ‘C’ in rainfed condition were found significant, which indicated the presence of epistatic interactions in both the conditions. Significance of joint scaling test indicated that non-additive interactions were present in this cross (Table 4.4.9). Only additive x additive (i) interaction was significant in irrigated condition, while in rainfed additive (d), dominance (h), additive x additive (i) and dominance x dominance (l) were significant. Among the significant parameters, (i) in irrigated and (l) in rainfed condition contributed more to the inheritance of the trait. Duplicate type of epistasis was recorded in rainfed condition since both (h) and (l) had significant values and opposite signs. No conclusion could be drawn regarding type of epistasis in irrigated condition since (h) was non-significant.

4.2.10 100-Seed weight (g)

RSG-895 x RSG-888

Significance of individual test ‘D’ and χ^2-values of joint scaling test indicated the presence of non-allelic interactions under both irrigated and

rainfed conditions (Table 4.4.10). Therefore, five-parameter model was fitted to estimate the gene effects and their interactions. Additive effect (d) and additive x additive (i) were found significant in irrigated and rainfed condition, respectively. The significant parameter (d) contributed maximum to the inheritance of trait in irrigated and parameter (i) in rainfed condition. No conclusion could be drawn regarding type of epistasis in both the conditions, since both (h) and (l) were non-significant.

RSG-888 x ICC-4958

Since the G x E variance was found to be non-significant in this cross, therefore, results have been described on the basis of pooled data over environments (irrigated and rainfed). Individual scaling tests 'C' and 'D' were found significant in this cross. The χ^2-values of joint scaling test provide evidence for the presence of non-allelic interactions in pooled analysis (Table 4.4.10). Among the components of five-parameter model, additive (d) and additive x additive (i) were observed significant. Both these parametes contributed towards genetic variation in this cross. No conclusion could be drawn regarding type of gene interaction as both (h) and (l) were non-significant in this cross.

IPC-94-94 x RSG-888

The significance of individual scaling test 'D' and χ^2-values of joint scaling test in pooled analysis over environments revealed inadequacy of additive-dominance model (Table 4.4.10). Additive (d) and additive x additive (i) effects were found significant in pooled analysis of this cross. Both these significant parameters thus contributed towards genetic variation in this cross. Since both (h) and (l) were non-significant no conclusion could be drawn about type of epistasis.

CSJD-901 x RSG-931

Individual as well as joint scaling tests revealed the inadequacy of additive-dominance model under both the conditions (Table 4.4.10). Among the components of five-parameter model, additive (d) in irrigated and additive x additive (i) in rainfed condition were found significant. Thus, significant parameter (d) in irrigated and (i) in rainfed contributed towards genetic variation. No conclusion could be drawn regarding type of epistasis, since,both (h) and (l) were non-significant in both the conditions.

BG-362 x RSG-931

Both individual scaling tests 'C' and 'D' were found significant in pooled analysis over environments, which indicated the presence of epistasis in this

cross. The significant χ^2-values of joint scaling test also supported the results of individual scaling tests (Table 4.4.10). Additive (d) and additive x additive (i) components were significant in pooled analysis of this cross. Both of these significant components contributed to the inheritance of the character in this cross. No conclusion could be drawn regarding type of gene action, since both (h) and (l) were found non-significant in this cross.

4.2.11 Protein content (%)

RSG-895 x RSG-888

The results have been described on the basis of pooled data over environments, since G x E variance was non-significant in this cross. In pooled analysis over environments, scaling test 'C' and 'D' were found significant and indicated the presence of non-allelic interactions. The result of joint scaling test was also in agreement with the individual scaling tests (Table 4.4.11). Main effects additive (d) and dominance (h) and interaction effect additive x additive (i) exhibited significant values in pooled analysis over environments. The significant parameter (i) followed by (h) contributed maximum to the mean performance of the character in this cross. No conclusion could be drawn regarding type of gene interaction since (l) was non- significant in this cross.

RSG-888 x ICC-4958

The significance of individual scaling test 'D' as well as χ^2-values of joint scaling test in pooled analysis over environments, indicated the inadequacy of additive-dominance model in this cross (Table 4.4.11). Among the components of five parameter model additive (d), additive x additive (i) and dominance x dominance (l) were significant in pooled over the environments. Among the significant parameters, (l) followed by (i) had maximum influence on the inheritance of character. No conclusion could be drawn regarding type of epistasis since (h) was non-significant.

IPC-94-94 x RSG-888

The scale 'C' and 'D' were significant in both irrigated and rainfed conditions indicated the presence of epistasis. The significant χ^2-values of joint scaling test were also in agreement with the results of individual scaling tests (Table 4.4.11). Therefore, five-parameter model was fitted to estimate the gene effects and interaction effects. Additive (d) effect and additive x additive (i) interaction effect had significant values in both the conditions,

whereas dominance (h) effect and dominance x dominance (l) interaction had significant values in irrigated only. The parameter (i) contributed more to the inheritance of the character under both the conditions. Duplicate type gene action was observed in irrigated condition, since the values of (h) and (l) were significant and had opposite signs.

CSJD-901 x RSG-931

Individual scaling test 'C' under both the conditions and scaling test 'D' under rainfed condition were significant indicating the presence of epistasis in both the conditions. The χ^2-values of joint scaling test were also supported the results of individual scaling tests (Table 4.4.11). In five parameter model components, additive (d) and additive x additive (i) under both the conditions and dominance (h) and dominance x dominance (l) only under irrigated were found significant. Among the significant parameters, (l) followed by (i) in irrigated and parameter (i) in rainfed condition had maximum influence on the inheritance of character. The significant and opposite signs of (h) and (l) values, indicated the presence of duplicate type of gene interaction in irrigated condition only.

BG-362 x RSG-931

Individual scaling test 'D' and χ^2-values of joint scaling test were found significant under both the conditions indicating the inadequacy of additive-dominance model (Table 4.4.11). Additive (d), dominance (h) and additive x additive (i) effects were found significant under both the conditions. Among the significant parameters, (i) contributed maximum to the inheritance of the trait under both the conditions. No conclusion could be drawn regarding type of epistasis under both the conditions, since (l) was non-significant.

4.3 Heterosis and inbreeding depression

Heterosis over mid parent and better parent in F_1 and inbreeding depression from F_1 to F_2 were measured in all the crosses for all the characters in both the conditions. The obtained results along with components of heterosis are presented in Table 4.5.1 to 4.5.11 and described character wise below:

4.3.1 Days to 50% flowering

In chickpea earliness in flowering is desirable. Heterosis over mid parent ranged from -0.17 per cent (BG-362 x RSG-931) to 11.06 per cent (IPC-94-94 x RSG-888) under irrigated and from -7.31 per cent (IPC-94-94 x RSG-888) to 2.58 per cent (BG-362 x RSG-931) under rainfed condition (Table 4.5.1). All the crosses exhibited significant heterosis over mid parent under both the conditions except BG-362 x RSG-931 under irrigated. Among them, significant and negative heterosis over mid parent was observed in all the crosses only under rainfed condition except BG-362 x RSG-931, which showed significant positive value. The negative magnitude of mid parent heterosis, indicated the superiority of F_1 to mid parent.

Heterosis over better parent (heterobeltiosis) ranged from 2.17 per cent (BG-362 x RSG-931) to 32.49 per cent (IPC-94-94 x RSG-888) under irrigated and from -1.23 per cent (RSG-895 x RSG-888) to 8.86 per cent (IPC-94-94 x RSG-888) under rainfed condition. All the crosses under both the conditions exhibited significant heterobeltiosis except CSJD-901 x

RSG-931 under rainfed. Among them, desirable significant and negative heterobeltiosis was observed only in RSG-895 x RSG-888 under rainfed condition. The positive magnitude of heterobeltiosis in most of the crosses, indicated the inferiority of F_1 (delayed flowering) to the better parent.

Evaluation across both the conditions indicated that RSG-895 x RSG-888 showed earliness in flowering over mid parent as well as over better parent under rainfed condition.

Inbreeding depression ranged from -1.06 per cent (BG-362 x RSG-931) to 1.76 per cent (RSG-895 x RSG-888) under irrigated and from -1.78 per cent (CSJD-901 x RSG-931) to 4.79 per cent (IPC-94-94 x RSG-888) under rainfed condition. Significant and positive inbreeding depression was observed in RSG-895 x RSG-888 under irrigated condition and in RSG-888 x ICC-4958 and IPC-94-94 x RSG-888 under rainfed, indicated that flowering in F_2 occurred earlier than F_1. Significant and negative inbreeding depression was observed in RSG-895 x RSG-888 and CSJD-901 x RSG-931 under rainfed and in BG-362 x RSG-931 under both the conditions, indicated that F_2 was comparatively late in flowering than F_1.

Components of heterosis revealed that (l) followed by (h) and (i) under irrigated and (l) followed (i) under rainfed condition contributed more towards better parent heterosis in most of the crosses. The opposite signs of (h) and (l) components in all the crosses under both the conditions could reduce the heterosis effect.

4.3.2 Days to maturity

The earliness is desirable for this trait, which is reflected by negative direction of heterosis. Heterosis over mid parent ranged from –1.35 per cent (BG-362 x RSG-931) to 2.91 per cent (CSJD-901 x RSG-931) under irrigated and from -1.27 per cent (IPC-94-94 x RSG-888) to 3.84 per cent (BG-362 x RSG-931) under rainfed condition (Table 4.5.2). Under both the conditions, all the five crosses exhibited significant heterosis over mid parent. Among them, significant and negative heterosis over mid parent was observed in the crosses RSG-888 x ICC-4958 and BG-362 x RSG-931 under irrigated and in IPC-94-94 x RSG-888 under rainfed condition, indicated superiority of F_1 over mid parent.

Heterobeltiosis ranged from 1.73 per cent (RSG-888 x ICC-4958) to 13.07 per cent (IPC-94-94 x RSG-888) under irrigated and from 4.70 per cent (BG-362 x RSG-931) to 11.19 per cent (IPC-94-94 x RSG-888) under rainfed condition. All the five crosses exhibited significant and positive heterobeltiosis under both the conditions, indicated inferiority (late maturity) of F_1 to the better parent, which is not desirable.

Inbreeding depression ranged from -0.81 per cent (IPC-94-94 x RSG-888) to 0.49 per cent (CSJD-901 x RSG-931) under irrigated and from 1.00 per cent (BG-362 x RSG-931) to 1.72 per cent (IPC-94-94 x RSG-888) under rainfed condition. Under irrigated condition inbreeding depression was found non-significant in all the crosses except RSG-888 x ICC-4958, which exhibiting significant and negative inbreeding depression. Under rainfed condition all the five crosses exhibited significant and positive inbreeding depression, indicated that F_2 was early in maturity as compared to F_1, which is desirable for this trait.

Evaluation of components of heterosis revealed that (l) followed by (i) and (h) under irrigated and (l) followed (h) under rainfed condition contributed more towards the better parent heterosis in most of the crosses except IPC-94-94 x RSG-888 where (i) followed by (l) and (d) contributed more. The opposite signs of (h) and (l) components in all the crosses under both the conditions could reduce the heterosis effect.

4.3.3 Plant height (cm)

In chickpea where lodging not a problem as in rainfed areas increase in height in some extent may results in higher yield provided podding starts from the lower nodes. Increase in height is associated with positive heterosis. Heterosis over mid parent ranged from -0.35 per cent (RSG-888 x ICC-4958) to 12.02 per cent (CSJD-901 x RSG-931) under irrigated and from 4.48 per cent (BG-362 x RSG-931) to 9.68 per cent (CSJD-901 x RSG-931) under rainfed condition (Table 4.5.3). All the crosses exhibited significant heterosis over mid parent under both the conditions except RSG-888 x ICC-4958 and IPC-94-94 x RSG-888 under irrigated and all of them were showing mid parent heterosis in positive direction.

Heterobeltiosis ranged from -10.26 per cent (IPC-94-94 x RSG-888) to 7.18 per cent (RSG-895 x RSG-888) under irrigated and from –5.47 per cent (BG-362 x RSG-931) to 7.57 per cent (CSJD-901 x RSG-931) under rainfed condition. All the crosses exhibited significant heterobeltiosis under both the conditions except RSG-895 x RSG-888 and IPC-94-94 x RSG-888 under irrigated condition. Among them, significant and positive heterobeltiosis was observed in RSG-895 x RSG-888 and BG-362 x RSG-931 under irrigated and in RSG-888 x ICC-4958 under rainfed and in CSJD-901 x RSG-931 under both the conditions.

Inbreeding depression ranged from -3.85 per cent (IPC-94-94 x RSG-888) to 3.34 per cent (CSJD-901 x RSG-931) under irrigated and from 0.16 per cent (BG-362 x RSG-931) to 4.28 per cent (IPC-94-94 x RSG-888) under rainfed condition. Inbreeding depression was found non-significant in all the crosses under both the conditions.

Evaluation of components of heterosis revealed that (l) followed by (i) and (h) under irrigated and (l) followed (h) under rainfed condition contributed more towards the better parent heterosis in most of the crosses. The opposite signs of (h) and (l) components in all the crosses under both the conditions could reduce the heterosis effect.

4.3.4 Fruiting branches per plant

The higher positive magnitude of this trait is desirable. Heterosis over mid parent ranged from 27.36 per cent (BG-362 x RSG-931) to 33.31 per cent (IPC-94-94 x RSG-888) under irrigated and from 11.53 per cent (RSG-895 x RSG-888) to 23.00 per cent (IPC-94-94 x RSG-888) under rainfed condition (Table 4.5.4). All the five crosses exhibited significant and positive heterosis over mid parent under both the conditions indicated the superiority of F_1 in comparison to mid parent.

Heterobeltiosis varied from 16.03 per cent (IPC-94-94 x RSG-888) to 21.63 per cent (RSG-895 x RSG-888) under irrigated and from -4.09 per cent (RSG-895 x RSG-888) to 10.62 per cent (CSJD-901 x RSG-931) under rainfed condition. Under irrigated condition all

the five crosses exhibited desirable significant and positive heterobeltiosis, whereas under rainfed heterobeltiosis was non-significant and positive in all the crosses except RSG-895 x RSG-888, which having non-significant and negative value. Absence of heterobeltiosis under rainfed condition might be due to internal cancellation of heterosis components. The highest significant positive heterobeltiosis was observed in RSG-895 x RSG-888 followed by BG-362 x RSG-931 and RSG-888 x ICC-4958 under irrigated condition.

Inbreeding depression ranged from 3.55 per cent (RSG-895 x RSG-888) to 11.82 per cent (CSJD-901 x RSG-931) under irrigated and from -1.54 per cent (CSJD-901x RSG-931)) to 7.41 per cent (BG-362 x RSG-931) under rainfed condition. Inbreeding depression was found non-significant in all the crosses under both the conditions except CSJD-901x RSG-931 under irrigated, where it was significant and positive. All the crosses except CSJD-901x RSG-931 exhibiting significant and positive better parent heterosis with non-significant inbreeding depression under irrigated condition, which is desirable.

Evaluation of components of heterosis revealed that (l) followed by (h) and (i) under irrigated and (l) followed (i) under rainfed condition contributed more towards the better parent heterosis in most of the crosses. The opposite signs of (h) and (l) components, indicating duplicate type epistasis in all the crosses under both the conditions could reduce the heterosis effect.

4.3.5 Pods per plant

Higher value of pods per plant has positive effect on seed yield, hence, positive heterosis for this trait is desirable. Heterosis over mid parent varied from 18.42 per cent (RSG-888 x ICC-4958) to 32.80 per cent (RSG-895 x RSG-888) under irrigated and from 23.83 per cent (BG-362 x RSG-931) to 39.41 per cent (RSG-895 x RSG-888) under rainfed condition (Table 4.5.5). All the crosses exhibited significant and positive heterosis over mid parent under both the conditions, indicating superiority of F_1 over mid parent.

Heterobeltiotic response ranged from 10.87 per cent (IPC-94-94 x RSG-888) to 16.02 per cent (RSG-895 x RSG-888) under irrigated and from 13.80 per cent (BG-362 x RSG-931) to 30.85 per cent (RSG-895 x RSG-888) under rainfed condition. All the crosses exhibited significant and positive heterobeltiosis under both the conditions, which is desirable.

The extent of inbreeding depression varied from 3.29 per cent (RSG-888 x ICC-4958) to 6.87 per cent (CSJD-901 x RSG-931) under irrigated and from -17.94 per cent (CSJD-901x RSG-931) to 9.89 per cent (IPC-94-94 x RSG-888) under rainfed condition. Inbreeding depression was found non-significant in all the crosses under both the conditions except in IPC-94-94 x RSG-888 and CSJD-901x RSG-931 under rainfed condition. IPC-94-94 x RSG-888 and CSJD-901x RSG-931 had significant positive and significant negative inbreeding depression, respectively. The highest heterosis over mid parent and better parent along with non-signifcant inbreeding depression was observed in RSG-895 x RSG-888 followed by CSJD-901x RSG-931 under irrigated and in RSG-895 x RSG-888 followed by RSG-888 x ICC-4958 under rainfed condition.

Evaluation of components of heterosis revealed that (l) followed by (i) and (h) under irrigated and (l) followed (h) and (i) under rainfed condition contributed maximum towards the better parent heterosis in most of the crosses. Further, the opposite signs of (h) and (l) components, indicating duplicate type of epistasis in all the crosses under both the conditions could reduce the heterosis effect.

4.3.6 Seeds per pod

. The heterotic response over mid parent for this character ranged from -5.96 to 9.26 per cent across both the conditions including pooled analysis over environments. Heterosis over mid parent was found non-significant in all the crosses under both the conditions as well as in pooled analysis over environments (Table 4.5.6).

Heterobeltiosis for this character ranged from -13.20 to 5.99 per cent across both the conditions including pooled analysis over environments. Heterobeltiosis was found non-significant in all the crosses under both the conditions as well as in pooled analysis over environments except in RSG-888 x ICC-4958 under pooled analysis over environments and in CSJD-901 x RSG-931 under irrigated condition, where it was significant and negative.

Inbreeding depression for this character across both the conditions including pooled analysis over environments ranged from -6.45 to 5.65 per cent. Inbreeding depression similar to mid parent heterosis was found non-significant in all the crosses under both the conditions as well as in pooled analysis over environments.

4.3.7 Biological yield per plant (g)

Heterosis over mid parent ranged from 16.29 per cent (RSG-895 x RSG-888) to 19.81 per cent (RSG-888 x ICC-4958) under irrigated and from 2.11 per cent (CSJD-901x RSG-931) to 28.53 per cent (RSG-888 x ICC-4958) under rainfed condition (Table 4.5.7). All the crosses exhibited desirable significant and positive heterosis over mid parent under both the conditions except BG-362 x RSG-931 under rainfed, which exhibited non-significant and positive heterosis over mid parent.

Heterobeltiosis ranged from 9.24 per cent (RSG-895 x RSG-888) to 13.51 per cent (IPC-94-94 x RSG-888) under irrigated and from –5.96 per cent (CSJD-901x RSG-931) to 19.98 per cent (RSG-888 x ICC-4958) under rainfed condition. All the crosses exhibited significant heterobeltiosis under both the conditions except RSG-895 x RSG-888 and CSJD-901x RSG-931 under rainfed and all of them were showing heterobeltiosis in positive direction, which is desirable. RSG-895 x RSG-888 and CSJD-901x RSG-931 crosses exhibited non-significant positive and non-significant negative under rainfed condition, respectively. The highest heterobeltiosis for biological yield per plant was observed in IPC-94-94 x RSG-888 followed by RSG-888 x ICC-4958 and BG-362 x RSG-931 under irrigated and in RSG-888 x ICC-4958 followed by IPC-94-94 x RSG-888 under rainfed condition.

Inbreeding depression ranged from -2.77 per cent (BG-362 x RSG-931) to 10.08 per cent (CSJD-901 x RSG-931) under irrigated and from -9.33 per cent (CSJD-901 x RSG-931) to 7.94 per cent (IPC-94-94 x RSG-888) under rainfed condition. Inbreeding depression was

found non-significant in all the crosses under both the conditions except CSJD-901 x RSG-931 under irrigated. The non-significance of inbreeding depression is desirable for this trait. The higher positive heterobeltiosis with non-significant inbreeding depression was observed in RSG-888 x ICC-4958 and IPC-94-94 x RSG-888 under both the conditions.

Evaluation of components of heterosis revealed that (l) followed by (h) and (i) under irrigated and (l) followed (i) and (h) under rainfed condition contributed maximum towards the better parent heterosis in most of the crosses. The opposite signs of (h) and (l) components in all the crosses under both the conditions could reduce the heterosis effect.

4.3.8 Seed yield per plant (g)

Higher seed yield per plant is desirable, which is reflected by positive heterosis. Heterosis over mid parent ranged from 21.16 per cent (IPC-94-94 x RSG-888) to 34.25 per cent (RSG-888 x ICC-4958) under irrigated and from 14.95 per cent (CSJD-901x RSG-931) to 46.39 per cent (RSG-888 x ICC-4958) under rainfed condition (Table 4.5.8). All the five crosses exhibited highly significant and positive heterosis over mid parent under both the conditions, indicating superiority of F_1 over mid parent.

Heterobeltiosis ranged from 12.57 per cent (IPC-94-94 x RSG-888) to 25.71 per cent (RSG-888 x ICC-4958) under irrigated and from 6.42 per cent (CSJD-901x RSG-931) to 31.63 per cent (RSG-888 x ICC-4958) under rainfed condition. The desirable significant and positive heterobeltiosis was observed in all the crosses under both the conditions except CSJD-901 x RSG-931 under rainfed, which exhibited non-significant positive heterobeltiosis. Non-significant heterobeltiosis in CSJD-901 x RSG-931 might be due to internal cancellation of components of heterosis.

Inbreeding depression ranged from 4.53 per cent (BG-362 x RSG-931) to 18.42 per cent (CSJD-901 x RSG-931) under irrigated and from -3.42 per cent (CSJD-901 x RSG-931) to 10.74 per cent (IPC-94-94 x RSG-888) under rainfed condition. Inbreeding depression was found non-significant in all the crosses under both the conditions except CSJD-901 x RSG-931 under irrigated. The highest positive heterobeltiosis with non-significant inbreeding depression was observed in RSG-888 x ICC-4958 followed by BG-362 x RSG-931 and RSG-895 x RSG-888 under both the conditions.

Evaluation of components of heterosis revealed that (l) followed by (i) and (h) under irrigated and (l) followed (h) and (i) under rainfed condition contributed maximum towards the better parent heterosis in most of the crosses. The opposite signs of (h) and (l) components in all the crosses under both the conditions, indicated duplicate type of epistasis and results in reduction of the heterosis effect.

4.3.9 Harvest index (%)

Higher value of harvest index is desirable. Heterosis over mid parent ranged from 11.05 per cent (CSJD-901 x RSG-931) to 16.91 per cent (RSG-888 x ICC-4958) under irrigated and from 8.51 per cent (CSJD-901x RSG-931) to 23.07 per cent (BG-362 x RSG-931) under rainfed condition (Table 4.5.9). In all the crosses heterosis over mid parent was

found significant and positive under both the conditions, indicating superiority of F_1 over mid parent.

Heterobeltiosis ranged from 8.02 per cent (IPC-94-94 x RSG-888) to 11.96 per cent (BG-362 x RSG-931) under irrigated and from 4.21 per cent (CSJD-901x RSG-931) to 14.65 per cent (BG-362 x RSG-931) under rainfed condition. Significant and positive heterobeltiosis was observed in all the crosses under both the conditions except CSJD-901 x RSG-931 under rainfed, which exhibited non-significant and positive heterobeltiosis. The significant and positive heterobeltiosis is desirable for this trait.

Inbreeding depression ranged from 1.26 per cent (IPC-94-94 x RSG-888) to 4.98 per cent (BG-362 x RSG-931) under irrigated and from 3.63 per cent (BG-362 x RSG-931) to 6.05 per cent (RSG-895 x RSG-888) under rainfed condition. Inbreeding depression was found non-significant in all the crosses under both the conditions except in IPC-94-94 x RSG-888 and CSJD-901 x RSG-931 under rainfed condition, which had significant and positive inbreeding depression. The higher magnitude of positive heterobeltiosis along with low inbreeding depression was observed in BG-362 x RSG-931, RSG-888 x ICC-4958 and CSJD-901 x RSG-931 under irrigated, whereas under rainfed it was observed in BG-362 x RSG-931, RSG-888 x ICC-4958 and RSG-895 x RSG-888.

Evaluation of components of heterosis revealed that (l) followed by (h) and (i) under irrigated and (l) followed (i) and (h) under rainfed condition contributed more towards the better parent heterosis in most of the crosses. The opposite signs of (h) and (l) components in all the crosses under both the conditions, indicated duplicate type of epistasis and results in reduction of the heterosis effect.

4.3.10 100-seed weight (g)

Higher positive magnitude of this trait is desirable. The range of heterosis over mid parent for this character across both the conditions including pooled analysis over environments ranged from 3.30 to 24.93 per cent. Heterosis over mid parent was found significant and positive in crosses CSJD-901 x RSG-931 under irrigated condition and in RSG-888 x ICC-4958, IPC-94-94 x RSG-888 and BG-362 x RSG-931 under pooled analysis over environments (Table 4.5.10).

Heterobeltiosis for this character across both the conditions including pooled analysis over environments ranged from -9.89 to 6.27 per cent. Significant and negative heterobeltiosis was observed in RSG-888 x ICC-4958 and IPC-94-94 x RSG-888 under pooled analysis over environments, which is undesirable for this trait. None of the crosses exhibited desirable significant and positive heterobeltiosis under both the conditions as well as in pooled analysis over environments.

Inbreeding depression for this character ranged from 1.16 to 4.05 per cent across both the conditions including pooled analysis over environments. Non-significant inbreeding depression was observed in all the crosses under both the conditions as well as in pooled

analysis over environments. Components of heterosis revealed that (i), (d) and (l) contributed towards significant the better parent heterosis in most of the crosses.

4.3.11 Protein content (%)

The higher seed protein content is desirable. The heterosis over mid parent across both the conditions including pooled analysis over environments for this character ranged from -5.49 to 6.68 per cent. Significant and positive heterosis over mid parent was observed only in cross RSG-888 x ICC-4958 under pooled analysis over environments, whereas significant and negative mid parent heterosis was found in CSJD-901 x RSG-931 under rainfed and in IPC-94-94 x RSG-888 under both irrigated and rainfed conditions (Table 4.5.11).

Heterobeltiosis for this character across both the conditions including pooled analysis over environments ranged from -10.03 to 2.82 per cent. All the crosses exhibited significant heterobeltiosis under both the conditions as well as in pooled analysis over environments except BG-362 x RSG-931 under rainfed condition. Among them, desirable significant and positive heterobeltiosis was observed only in RSG-888 x ICC-4958 under pooled over environments.

Inbreeding depression for this character across both the conditions including pooled analysis over environments ranged from -0.92 to 3.90 per cent. Inbreeding depression was found non-significant in all the crosses under both the conditions as well as in pooled analysis over environments except RSG-888 x ICC-4958 under pooled and BG-362 x RSG-931 under irrigated, which had significant and positive inbreeding depression.

Evaluation of components of heterosis revealed that (i) followed by (l) and (h) contributed maximum towards the better parent heterosis in most of the crosses under both the conditions. The opposite signs of (h) and (l) components in most of the crosses under both the conditions as well as in pooled analysis over environments could reduce the heterosis effect.

5. DISCUSSION

The chickpea is an important pulse crop for our country. It constitutes an important source of dietary protein and is a rich source of energy, minerals and certain vitamins. Chickpea production has remained static for last three decades; the area and production of this have been around 7.0 million hectares and 5.0 million tonnes, respectively with virtually stagnant productivity of 6-7q/ha. The major limiting factor has been the susceptibility of cultivars to different biotic and abiotic stresses that adversely affect the yield. Although progress towards alleviating biotic stresses affecting chickpea productivity has been satisfactory, the work on abiotic stresses needs immediate attention. The most important abiotic stress is the drought, which severely affects the productivity of chickpea under rainfed production system.

Information on the genetic parameters associated with the inheritance of a character is a prerequisite to plan a sound-breeding programme aimed at improvement of the trait. The breeder of the self-pollinated crop like chickpea will have to lay more weightage to the exploitation of additive gene action. Additive x additive epistasis, which can be exploited in homozygous state is also of considerable value. The drought conditions under which chickpeas are generally grown impose restrictions on the expression of genetic yield potential. Hence, the present study was undertaken to assess the nature and magnitude of the gene actions for seed yield and its components in chickpea under irrigated and rainfed conditions such information on chickpea over environments is scanty. Chickpea varieties selected for the present investigation were based on drought tolerance, seed size as well as diversity for yield and its components and morphological traits. Inheritance of different traits in the present investigation was traced out through generation mean analysis.

The results obtained during the present investigation are discussed under the light of the available knowledge on the subject.

5.1 Analysis of variance and *per se* performance

The means of five generations of all the five crosses under both irrigated and rainfed conditions were subjected to analysis of variance. Significant differences among the crosses were observed for all the characters under both irrigated and rainfed conditions, indicating sufficient diversity among the crosses. The generation mean sum of squares for all the characters were significant in all the crosses under irrigated as well as under rainfed condition, indicated sufficient genetic diversity among the generations. The pooled analysis of variance revealed that there were significant differences among environments in all the crosses for all the characters except for seeds per pod in RSG-888 x ICC-4958 and BG-362 x RSG-931. Significant differences between the environments, indicated the effect of environment on expression of characters. Generation x environment interaction was 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-888x

ICC-4958, IPC-94-94 x RSG-888 and BG-362 x RSG-931 and for protein content in RSG-895 x RSG-888 and RSG-888 x ICC-4958. The significance of G x E showing differential response of irrigated and rainfed conditions.

Range for most of the observed characters was relatively wider in the irrigated condition in comparison to rainfed condition (Table 4.3.12). Comparison of mean values of different traits indicated that the means of various characters were lower under rainfed condition except for protein content, which might be due to terminal drought, moisture and heat stress. However, there was no marked reduction in harvest index. This is in agreement with Dhiman *et al.* (2006) who also reported increased harvest index under rainfed condition. Increase in protein content under rainfed condition can be ascribed to reduction in seed size and more assimilation of amino acids in rainfed condition. A considerable reduction in yield and associated traits under rainfed condition also reported by Siva Kumar *et al.* (2004), Ozgun *et al.* (2004), Sanap *et al.* (2004) and Dhiman *et al.* (2006). In general, maximum reduction was observed for pods per plant followed by seed yield per plant, biological yield per plant, fruiting branches per plant and plant height, thus, it can be said that these characters were more sensitive to moisture stress. Seeds per pod and 100-seed weight were not significantly affected by moisture stress under rainfed condition. Kumar *et al.* (2004) also observed non-significant effect of moisture stress on seeds per pod and 100-seed weight. The mean values for seed yield per plant under rainfed condition were reduced by 16.10 per cent in parents, 12.62 per cent in F_1s, 11.41 per cent in F_2s and 12.21 per cent in F_3s. The detrimental effect of moisture stress in rainfed condition on seed yield was maximum through reduction in fruiting branches per plant, pods per plant, biological yield per plant and plant height (Table 4.3.13). Thus, these characters should be given more consideration while deciding selection criteria for rainfed condition. Under rainfed condition the poor seed yield of genotypes may be attributed to poor biomass production coupled with low harvest index. Muhammad *et al.* (2004) also reported high direct effect of biological yield and harvest index on seed yield under rainfed condition.

The results also revealed that the parents IPC-94-94, RSG-895 and CSJD-901 flowered earlier and also matured earlier, even in rainfed condition and imparted the early flowering and maturity even to their crosses. Cross IPC-94-94 x RSG-RSG-88 was observed to be earliest to flower and mature under both the conditions, which may be utilized for development of an early flowering and early maturing types. Although, a decrease in plant height was observed in all the generations in most of the crosses under rainfed condition but BG-362 was found to be least affected. BG-362 was observed to be tallest parent followed by RSG-888 and ICC-4958 under rainfed condition and imparted tallness to its crosses. Evaluation of performance across both the conditions revealed that bold seeded parents *viz.,* ICC-4958, BG-362 and IPC-94-94 and their crosses had higher mean values for yield and yield contributing characters *viz.,* plant height, fruiting branches per plant, pods per plant, seeds per pod, biological yield per plant, harvest index and 100-seed weight even in rainfed condition indicated that these parents and crosses were least affected by moisture stress in

rainfed and can be bred for drought tolerance. These findings support the findings of Kumar *et al.* (2004).

The highest seed yield and harvest index (%) were recorded in bold seeded parents IPC-94-94, ICC-4958 and BG-362 even in rainfed condition indicated that bold seeded genotypes generally showed higher degree of drought tolerance in comparison to medium seeded genotypes. Similar results also reported by Kumar *et al.* (2004) and Yadav *et al.* (2004).

The F_1 means varied from character to character and from cross to cross. The mean performance of F_1 for days to 50% flowering, days to maturity and seeds per pod was in between the parents in majority of cases under both the conditions, indicating partial dominance. For plant height, fruiting branches per plant, pods per plant, biological yield per plant, seeds per pod, harvest index, 100-seed weight and protein content F_1 means showed heterotic effect in most of crosses under both irrigated and rainfed conditions. Patil *et al.* (1987) also reported the similar findings for yield contributing characters. Among F_1s the highest mean value for seed yield per plant was observed in RSG-888 x ICC-4958 followed by BG-362 x RSG-931 and IPC-94-94 x RSG-888 even in rainfed condition and these crosses may be utilized for development of high yielding variety for rainfed condition. The F_2 means for majority of the characters were less than the F_1 means under both the conditions, indicating existence of inbreeding depression and role of dominance gene action in the inheritance. Patil *et al.* (1987) and Shinde and Deshmukh (1990) were also observed the role of dominance gene action for yield contributing characters. No definite trend was observed for F_3 means, however, they showed tendency towards their higher parent for different characters in most of the crosses under both the conditions.

5.2 Scaling tests

The test of epistasis is necessary before estimation of the components of genetic variation because it helps in deciding the method of analysis for the components of variation. Scaling tests determines (1) the presence or absence of non- allelic interactions and (2) their types.

The individual scaling tests ‘C’ and ‘D’ as well as joint scaling tests revealed the presence of epistatic interactions for all the characters in all the

crosses under both the conditions as well as in pooled analysis over environments (irrigated and rainfed). These indicated that genetic variation could not be ascribed only due to additive and dominance effects rather epistasis also played great role or additive-dominance model was not adequate to explain the genetic variation. Therefore, five-parameter model was used to determine the type and magnitude of gene actions involved in the inheritance of different characters in all the crosses.

5.3 Estimation of gene effects

5.3.1 Days to 50% flowering

Both main effects *i.e.,* additive (d) and dominance (h) were significant in all the crosses under both the conditions except for dominance in IPC-94-94 X RSG-888 under rainfed. The greater magnitude of dominance than additive component in most of crosses under both the conditions, indicating predominance of dominance effect in the inheritance of days to 50% flowering. Among interaction effects, additive x additive (i) interaction was significant in all the crosses under both the conditions except RSG-895 x RSG-888 and CSJD-901 x RSG-931 under irrigated condition. Dominance x dominance (l) effect was also significant in all the crosses under both the conditions (except IPC-94-94 x RSG-888 in irrigated condition). The higher magnitude of dominance x dominance (l) than additive x additive (i) in most of the crosses under both the conditions, indicated the importance of dominance x dominance (l) interaction for inheritance of this trait. In cross IPC-94-94 x RSG-888 both additive (d) and Additive x additive (i) effects were involved in the expression of this trait under both the conditions. These findings are in agreement with the findings of Singh and Ramanujam (1981), Padey and Tiwari (1989), Girase and Deshmukh (2000), Sarode *et al.* (2000), Patil *et al.* (2004) and Bhardwaj and Sandhu (2007). The relative magnitude of gene effects also confirmed the importance of dominance (h) and dominance x dominance (l) effects in expression of days to 50% flowering under both the conditions except IPC-94-94 x RSG-888. The duplicate epistasis was observed in all the crosses under both the conditions where (h) and (l) components were significant. Duplicate type of epistasis was also reported by Kidambi *et al.* (1988), Pandey and Tiwari (1989), Girase and Deshmukh (2000) and Bhardwaj and Sandhu (2007) in chickpea.

A perusal of main effects and absolute totals of epistatic effects (Table 5.1.1) revealed that absolute totals (ignoring the signs) of epistatic effects were higher in magnitude than the main effects in all the crosses under both the conditions. This indicated that non-allelic interactions played greater role in the inheritance of this trait. Earlier Singh and Ramanujam (1981), Pandey and Tiwari (1989) and Girase and Deshmukh (2000) and Bhardwaj and Sandhu (2007) also reported importance of non-allelic interactions in expression of this trait. The absolute totals of non-fixable gene effects were higher than fixable gene effects for this trait in all the crosses under both the conditions except IPC-94-94 x RSG-888 under both irrigated and rainfed and BG-362 x RSG-931 under rainfed. In conclusion, it can be said that non-fixable gene effects were more important than the fixable gene effects in the expression of this trait under both the conditions.

5.3.2 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. Similar, results were also reported by Singh and Ramanujam (1981), Pandey and Tiwari (1989), Shinde and Deshmukh (1990) Girase and Deshmukh (2000) and Bhardwaj and Sandhu (2007). Duplicate epistasis was revealed for the inheritance of this trait under both the conditions, which is in line with the reports of Patil *et al.* (1987), Pandey and Tiwari (1989), Shinde and Deshmukh (1990) and Girase and Deshmukh (2000).

The epistatic effects were more important than the main effects for the inheritance of this trait in all the crosses under both the conditions (Table

5.1.2). Absolute totals of non-fixable gene effects were higher than fixable gene effects in all the crosses under both the conditions except IPC-94-94 x RSG-888, indicating greater role of non-additive gene effects in the inheritance of this trait. Salimath and Bahl (1985), Shinde and Deshmukh (1990), Girase and Deshmukh (2000) and Bhardwaj and Sandhu (2007) also reported that non-additive type of gene effects were responsible for the inheritance of days to maturity.

5.3.3 Plant height (cm)

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 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. Singh and Ramanujam (1981), Kidambi *et al.* (1988), Mehla *et al.* (2000), Girase and Deshmukh (2000), Singh *et al.* (2001) and Bhardwaj and Sandhu (2007) reported that both additive and non-additive gene effects played important role in controlling this trait. Duplicate type of epistasis was observed under both the conditions where parameters (h) and (l) were significant, it would tend to reduce the heterosis effect. Mehla *et al.* (2000) and Bhardwaj and Sandhu (2007) also reported duplicate type of epistasis for plant height.

The absolute totals of main effects and epistatic effects (Table 5.1.3) indicated the importance of epistatic effects in the inheritance of this trait under both the conditions. Absolute totals also indicated the greater role of non-additive effect for the inheritance of plant height under both the conditions, since the non-fixable effects were higher than the fixable effects in all the crosses except RSG-888 x ICC-4958 and IPC-94-94 x RSG-888 under irrigated condition, In these crosses, plant height inherited by additive gene effects. Bhardwaj and Sandhu (2007) was also reported the importance of

non-additive effects, while Gupta *et al.* (2007) reported the importance of additive gene effects for this trait.

5.3.4 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 indicating, importance of dominance 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, with higher magnitude of dominance x dominance (l) than additive x additive effect, indicated the importance of dominance x dominance effect. The importance of (h) and (l) were also reported by Patil *et al.* (1987), Shinde and Deshmukh (1990), Girase and Deshmukh (2000), Bhardwaj and Sandhu (2007) and Gupta *et al.* (2007) for the inheritance of fruiting branches per plant. Duplicate epistasis was observed for the inheritance of this trait under both the conditions, which hinder the pace of progress. The importance of duplicate type of epistasis for fruiting branches also reported by Patil *et al.* (1987), Shinde and Deshmukh (1990) and Bhardwaj and Sandhu (2007).

The absolute totals of gene effects (Table 5.1.4) revealed that main effects as well as epistatic effects were more important than the main effects for the inheritance of this trait in all the crosses under both conditions. The absolute totals of non-fixable effects were higher than fixable gene effects in all the crosses under both the conditions, indicating role of non-additive gene effects in controlling this character. The importance of non-additive gene effects were also reported by Singh and Ramanujam (1981), Patil *et al.* (1987), Girase and Deshmukh (2000), Bhardwaj and Sandhu (2007) and Gupta *et al.* (2007) in controlling of fruiting branches per plant.

5.3.5 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. The duplicate epistasis was observed in all the crosses in both the conditions for the inheritance of this trait where, (h) and (l) were found significant. Singh and Ramanujam (1981), Pandey and Tiwari (1989), Shinde and Deshmukh (1990), Patil *et al.* (1998a), Sarode *et al.* (2000), Mehla *et al.* (2000), Patil *et al.* (2004) and Gupta *et al.* (2007) also reported the same findings for the inheritance of pods per plant.

Absolute totals of main and interaction effects confirmed the importance of both main and epistaic effects in the expression of this trait (Table 5.1.5). However, epistatic effects played major role in controlling the inheritance of this trait in all the crosses under both the conditions. Preponderance of non-fixable gene effects indicated the importance of non-additive gene effects. Sarode *et al.* (2000), Patil *et al.* (2004), Gupta *et al.* (2006) and Gupta *et al.* (2007) also reported preponderance of non-additive gene effects for pods per plant.

5.3.6 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. Bhardwaj and Sandu (2007) and Gupta *et al.* (2007) also emphasized the 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 over environments, indicating the importance of additive x additive (i)effect in the inheritance of this trait. Singh and Ramanujam (1981), Singh *et al.* (1994) and Bhardwaj and Sandhu (2007) also reported the similar results. In all the cases, where epistasis was significant, it was duplicate epistasis. Patil *et al.* (1998a) and Bhardwaj and Sandhu (2007) also reported duplicate epistasis for this trait.

The absolute totals of main effects and interaction effects (Table 5.1.6) confirmed the importance of both main and epistatic effects in the expression of this trait under both the conditions. However, epistatic effects played major role in controlling the inheritance of seeds per pod. Preponderance of non-fixable gene effects were observed due to internal cancellation of gene effects, which indicated the importance of non-additive gene effects. Singh and Ramanujam (1981), Pandey and Tiwari (1989), Girase and Deshmukh (2000), Singh *et al.* (1994), Patil *et al.* (1998a) Gupta *et al.* (2006), Bhardwaj and Sandhu (2007) and Gupta *et al.* (2007) also reported the importance of non-additive gene effects for this trait.

5.3.7 Biological yield per plant

As 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, indicated predominance of dominance 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), indicated that dominance x dominance interaction played greater

role in controlling of this trait. Duplicate epistasis was observed in all the significant cases. This is in agreement with findings of Bhardwaj and Sandhu (2007).

The absolute totals of the main effects and epistatic effects (Table 5.1.7) indicated the importance of both main effects and epistatic effects in all the crosses under both the conditions, Perusal of absolute totals of fixable and non-fixable gene effects revealed the higher magnitude of non-fixable gene effects than fixable gene effects, indicated the importance of non-additive gene action in the inheritance of this trait. These findings well in agreement with the results of Gupta *et al.* (2006), Bhardwaj and Sandhu (2007) and Gupta *et al.* (2007).

5.3.8 Seed yield per plant

Both main effects *i.e.*, additive (d) and domionance (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, indicated the importance of dominance x dominance (l) interaction in controlling the inheritance of this trait. Duplicate epistasis was important in all the cases, where (h) and (l) were found significant. The findings of Singh and Ramanujam (1981), Patil *et al.* (1987), Pandey and Tiwari (1989), Shinde and Deshmukh (1990), Patil *et al.* (1998a), Girase and Deshmukh (2000), Mahla *et al.* (2000), Sarode *et al.* (2000), Bhaduoria *et al.* (2002), Patil *et al.* (2004), Gupta *et al.* (2006), Bhardwaj and Sandhu (2007) and Gupta *et al.* (2007) were in agreement to the present findings.

The absolute totals of main effects and epistatic effects (Table 5.1.8) showed that both main and epistatic effects were important for this trait in all the crosses under both the conditions with higher magnitude of epistatic effects than main effects, indicated greater role of non-allelic interactions in

the inheritance of this trait. It was also revealed that the non-fixable gene effects were higher than fixable ones, indicating involvement of non-additive type of gene action in the inheritance of seed yield per plant. Pandey and Tiwari (1989), Shinde and Deshmukh (1990), Annigeri *et al.* (1996), Jha *et al.* (1997), Patil *et al.* (1998a), Mahla *et al.* (2000), Girase and Deshmukh (2000), Singh *et al.* (2001), Bhaduoria *et al.* (2002), Patil *et al.* (2004), Gupta *et al.* (2006), Bhardwaj and Sandhu (2007) and Gupta *et al.* (2007) also reported the similar results.

5.3.9 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 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. Singh and Ramanujam (1981), Mandal (1992), Patil *et al.* (2004), Gupta *et al.* (2006), Bhardwaj and Sandhu (2007) and Gupta *et al.* (2007) also emphasized the importance of non-additive gene action in the inheritance of harvest index. Duplicate epistasis was noted in all the significant cases indicated hindrance in the progress of selection in early generation. These findings are in agreement to the findings of Bhardwaj and Sandu (2007).

The absolute totals of main and interaction effects (Table 5.1.9) confirmed the importance of both main and epistatic effects in the expression of this trait in all the crosses under both the conditions. However, epistatic effects played major role in controlling the inheritance of this trait. Preponderance of non-fixable gene effects indicated the importance of non-additive gene effects. These findings are in agreement to the findings of Singh

and Ramanujam (1981), Mandal (1992), Gupta *et al.* (2006), Bhardwaj and Sandhu (2007) and Gupta *et al.* (2007).

5.3.10 100-seed weight (g)

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. These findings are in agreement with the findings of Pati *et al.* (1987), Pandey and Tiwari (1989), Shinde and Deshmukh (1990), Kumar and Singh (1995), Patil *et al.* (1998a), Mehla *et al.* (2000), Sarode *et al.* (2000), Patil *et al.* (2004), Gupta *et al.* (2006) and Bhardwaj and Sandhu (2007).

The absolute totals of main and epistatic effects (Table 5.1.10) confirmed the importance of additive and epistatic effects in the expression of this trait. However, epistatic effects played major role in controlling the inheritance of this trait in most of crosses under both the conditions. Preponderance of fixable gene effects in most of the crosses indicated the importance of additive gene effects in inheritance of this trait. The low magnitudes of fixable gene effcets than non-fixable gene effects observed in two of the five crosses under both the conditions, which might be due to internal cancellation of gene effects. Earlier Patil *et al.* (1987), Pandey and Tiwari (1989), Shinde and Deshmukh (1990) Patil *et al.* (1998a), Girase and Deshmukh (2000), Mahla *et al.* (2000), Patil *et al.* (2004), Gupta *et al.* (2006) and Bhardwaj and Sandhu (2007) also reported the importance of additive gene effects in controlling of this trait.

5.3.11 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, indicated importance of additive x additive interaction for the inheritance of this trait. Patil *et al.* (1987) reported the importance of dominance (h) and additive x additive (i) gene effect in controlling the inheritance of protein content. Salimath *et al.* (1988) estimated non-additive variation to influence seed protein. The duplicate epistasis was observed in two cases where epistasis was significant. Patil *et al.* (1987) also reported duplicate type of epistasis in the inheritance of this trait.

The absolute totals of main effects and epistatic effects (Table 5.1.11) confirmed the importance of both main and epistatic effects in the expression of this trait with greater role of epistatic effects. Preponderance of fixable gene effects in most of the cases except CSJD-901 x RSG-931 under irrigated and BG-362 x RSG-931under rainfed condition, indicated the importance of additive gene effects for the inheritance of this trait which might be due to greater role of additive x additive interaction effect.

Perusal of the totals of gene effects (Table 5.2) in all the crosses and over both the conditions revealed that the main effects *i.e.,* additive (d) and dominance (h) expressed more frequently in irrigated condition. Therefore, it can be concluded that the expression of main effects needs optimum condition. The epistatic effects (i) and (l) expressed themselves more frequently in rainfed (in harsh condition) to create genetic variation.

5.4 Heterosis and inbreeding depression

In order to carry out successful heterosis breeding programme in any crop there are two important prerequisites,

(1) Evidence of the presence of significant heterotic effect in the hybrid that can be of practical utility and

(2) Production of hybrid seed on commercial scale must be economically feasible

Chickpea is a self-pollinated crop and a suitable mechanism to produce hybrid seed on commercial scale is not yet available. Therefore, at present heterosis per se may not be exploitable commercially. However, heterosis particularly superiority over better parent (heterobeltiosis) is important in deciding the direction of future breeding programme by identifying the cross combinations which may prove promising in conventional breeding programme. The results obtained with regard to heterosis over better parent and inbreeding depression are discussed here as under:

In the present investigation the expression of heterobeltiosis, in general, was variable for different traits under both the conditions. Early flowering and maturity are desirable to achieve higher yield in rainfed condition (Calcagno and Gallo, 1993 and Singh, 1997) but in the present study positive and significant heterobeltiosis was observed for days to 50% flowering and days to maturity in all the cases except for days to 50 % flowering in cross RSG-895 x RSG-888 and CSJD-901 x RSG-931 under rainfed condition, indicating superiority of better parent over hybrid, which is undesirable. The desirable significant and negative heterosis over better parent for days to 50 % flowering was recorded only in cross RSG-895 x RSG-888 under rainfed condition. This cross can be utilized for development of an early flowering variety. Significant and positive heterosis over better parent was also observed for plant height, fruiting branches per plant and biological yield per plant under irrigated, for pods per plant, seed yield per plant and harvest index under both irrigated and rainfed in cross RSG-895 x RSG-888; for pods per plant, biological yield per plant, seed yield per plant and harvest index under both irrigated and rainfed conditions, for plant height under rainfed, for fruiting branches per plant under irrigated and for protein content under pooled in RSG-888 x ICC-4958; for pods per plant, biological yield per plant, seed yield per plant and harvest index under both the conditions and for fruiting branches per plant under irrigated in cross IPC-94-94 x RSG-888; for fruiting branches per plant, biological yield per plant, seed yield per plant and harvest index under irrigated and for pods per plant and plant height under both conditions in cross CSJD-901 x RSG-931; for pods per plant, biological yield per plant, harvest index and seed yield per plant under both irrigated and rainfed, for plant height and fruiting branches per plant under irrigated in cross BG-362 x RSG-931. Plant height is an economic character in most of the crops. In chickpea, where lodging is not a problem as in rainfed areas, increase in height to some extent may results in higher yield provided podding starts from the lower nodes (Mehla *et al.*, 2000). In the present study significant and positive heterosis over better parent for plant height was observed in RSG-895 x RSG-888 and BG-

362 x RSG-931under irrigated; in RSG-888 x ICC-4958 under rainfed and in CSJD-901 x RSG-931 under both the conditions. For seed yield per plant significant and positive heterosis over better parent was observed in all the five crosses under both the conditions except for cross CSJD-901 x RSG-931 under rainfed. This heterosis was desirable as it indicated superiority of hybrid over better parent and may throw some transgressive segregants in the succeeding generations. Significant and negative heterosis over better parent was observed for days to 50% flowering under rainfed and for protein content under pooled in cross RSG-895 x RSG-888; for plant height under irrigated and for seeds per pod and 100-seed weight under pooled in RSG-888 x ICC-4958; for plant height under irrigated, for protein content under both irrigated and rainfed and for 100-seed weight under pooled in cross IPC-94-94 x RSG-RSG-888; for seeds per pod under irrigated and for protein content under both irrigated and rainfed in CSJD-901 x RSG-931, whereas in the cross BG-362 x RSG-931 significant and negative heterobeltiosis was recorded only for plant height under rainfed and for protein content under irrigated condition. Negative heterosis for yield and related traits is undesirable and may appear due to dominance of unfavorable gene or inhibitory gene action or internal cancellation of heterosis components. Absence of heterosis in certain other cases could be explained on the basis of internal cancellation of components of heterosis, which depends on the material under study. Earlier also heterosis and heterobeltiosis for one or the other yield and yield associated traits in chickpea have been reported by Maheshwari (1978), Singh and Mehra (1980), Deshmukh and Bhapkar (1982a, 1982b), Bhanushally (1984), Salimath and Bahl (1985), Salimath *et al.* (1988), Pandey and Tiwari (1989), Katiyar and Katiyar (1993), Patil *et al.* (1998b), Jeena and Arora (2000), Sarode *et al.* (2000), Sharif *et al.* (2001), Bhaduoria and Chaturvedi (2003), Gupta *et al.* (2003) and Hegde *et al.* (2007). The perusal of Table 5.13 revealed that the magnitude of heterobeltiosis was maximum for seed yield per plant followed by fruiting branches per plant, pods per plant and biological yield per plant under irrigated, whereas under rainfed it was maximum for seed yield per plant followed by pods per plant, biological yield per plant and harvest index. The low magnitude of heterobeltiosis for various characters in the present study may be due to internal cancellation of components of heterosis. It is of considerable interest to know the cause of heterosis for seed yield. Grafius (1959) suggested that there could be no separate gene system for yield per se as yield was an end product of multiplicative interactions between its various components. Thus, heterobeltiosis in different yield contributing characters may result in the expression of heterobeltiosis for seed yield. The heterobeltiosis for seed yield per plant in most of crosses was associated with heterobeltiosis for fruiting branches per plant, pods per plant, biological yield per plant and harvest index under irrigated, whereas under rainfed condition it was associated with heterobeltiosis for pods per plant, biological yield per plant. Harvest index and 100-seed weight, indicated that heterobeltiosis for seed yield mainly contributed by heterobeltiosis of these characters in respective environments (conditions). The results also revealed that the crosses RSG-888 x ICC-4958, BG-362 x RSG-931 and IPC-94-94 x RSG-888 involving bold seeded parents (ICC-4958, BG-362 and IPC-94-94) were found to be heterotic for yield and most of the yield contributing characters in irrigated as well as in rainfed condition. This supports the findings of Singh (1997).

The inbreeding depression is indirectly a manifestation of non-additive gene action controlling the character, which may require complicated breeding methodology for their exploitation or will demand exploitation of heterosis through hybrid varieties. Significant inbreeding depression was observed for seed yield and its attributes in this study but the degree of inbreeding depression as well as direction also differed. Significant and positive inbreeding depression was observed for days to 50% flowering under irrigated and for days to maturity and seed yield per plant under rainfed in the cross RSG-895 x RSG-888; for days to 50% flowering, days to maturity under rainfed and for protein content under pooled in cross RSG-888 x ICC-4958; for days to 50% flowering, days to maturity, pods per plant, and harvest index under rainfed in cross IPC-94-94 x RSG-888; for days to maturity and harvest index under rainfed and for fruiting branches per plant, biological yield per plant and seed yield per plant under irrigated in cross CSJD-901 x RSG-931; for days to maturity under rainfed and for protein content under irrigated in cross BG-362 x RSG-931. Positive inbreeding depression for days to 50% flowering and days to maturity showed possibility of selection of early flowering and early maturing new genotypes in subsequent generations. Kunadia and Singh (1980), Singh and Ramanujam (1981), Tewari and Pandey (1987), Pandey and Tiwari (1989), Singh *et al.* (2001), Sarode *et al.* (2000) and Bhaduoria and Chaturvedi (2003) were also observed the positive inbreeding depression for yield and associated traits in chickpea. Negative inbreeding depression was observed for some of the characters like days to 50% flowering under rainfed in crosses RSG-895 x RSG-888; days to maturity under irrigated in cross RSG-888 x ICC-4958; days to maturity and pods per plant under rainfed in cross CSJD-901 x RSG-931 and days to 50 % flowering under both irrigated and rainfed in cross BG-362 x RSG-931. Pandey and Tiwari (1989) and Singh *et al.* (2002) also reported negative inbreeding depression for days to flowering, days to maturity, fruiting branches, seed yield and 100-seed weight in chickpea. It may appear due to the favorable gene recombinations and may be useful in self-pollinated crops like chickpea for selection in advanced generations. On the basis of *per se* performance, heterosis and inbreeding depression it was concluded that the crosses RSG-888 x ICC-4958, BG-362 x RSG-RSG-931 and IPC-94-94 x RSG-888 involving bold seeded parents (ICC-4958, BG-362 and IPC-94-94) had high mean value, heterobeltiosis with least inbreeding depression from F_1 to F_2 generation for most of the yield contributing characters *viz.,* plant height, fruiting branches per plant, pods per plant, seeds per pod biological yield per plant, harvest index and 100-seed weight even in rainfed condition, thus, could be utilized in future breeding programme.

Plant breeding implications

The knowledge of genetic mechanisms that control response of genotypes to a particular edaphic stress factor like drought will not only help in evolving a suitable breeding methodology but also accelerate the pace of progress. The modern methods of biometrical and quantitative genetics may help in designing breeding methods in handling and evaluation of breeding

materials on a large scale and with greater precision and at the same time help to generate information on the inheritance of different traits in chickpea.

In the present investigation the experimental material was evaluated to obtain information on the significance of additive and non- additive gene action including inter-allelic interactions for different traits in chickpea under both irrigated and rainfed conditions. The results indicated that the magnitude as well as direction of additive (d) and dominance (h) effects and their interactions *i.e.,* additive x additive (i) and dominance x dominance (l) were affected by the environments (irrigated and rainfed), but no specific trend was observed. Such kind of behavior may be associated with the significant generation x environment interactions.

Additive, dominance and epistatic components were significant in most of the crosses under both the conditions for all the characters with preponderance of non-fixable gene effects, indicating complex type of inheritance, which limits the scope for improvement through selection. While, the additive gene effect and additive x additive (i) interaction were important for 100-seed weight in most of the crosses under both the conditions, indicated that this character could be improved upon selection in segregating generations. Significant and positive heterosis over better parent was also observed in all the crosses for seed yield per plant under both the conditions. This significant positive heterosis for seed yield was accompanied by significant positive heterosis for most of the yield contributing components along with significant inbreeding depression. Significant heterosis and inbreeding depression in any character represent the role of non-additive gene effects (Pawar *et al.*, 1985). The significant values and opposite signs of dominance (h) and dominance x dominance (l) for most of the traits under both the conditions, indicated the role of duplicate type of epistatsis.

The digenic interactions were more important than main effects. It was also apparent that in general the absolute totals of non-fixable gene effects were higher than the fixable gene effects for all the five crosses in both the conditions indicating role of non-additive gene action.

Therefore, some sort of recurrent selection by way of intermating the most desirable segregants followed by selection (Joshi, 1979), diallel selective mating methods (Jensen, 1970 and Frey, 1975) or the use of multiple crosses and bi-parental mating might prove to be

effective alternative approaches. In crops like chickpea, non-additive gene action can not be utilized in the form of hybrid vigour due to lack of biological feasibility to produce hybrid varieties, it is a best approach otherwise to exploit the non-additive gene action. Biparental matings would lead to break undesirable linkages and crossability barriers, which are perhaps the source of hindrance in realizing the desirable genetic recombinants, even when the parents have sufficient genetic diversity. Further more, the presence of duplicate type of epistasis as observed in generation mean analysis indicated that selection intensity should be mild in the earlier and intense in the later generations.

Such dynamic breeding approaches for handling all the five crosses used in the present investigation are expected to end up in some homozygous lines with appreciable yield levels in rainfed areas.

6. SUMMARY AND CONCLUSION

The present investigation entitled “Genetics of yield and yield components in chickpea (*Cicer arietinum* L.) under irrigated and rainfed conditions” was carried out at Research Farm, Agricultural Research Sub Station, Hanumangarh in compact family block design with three replications, to detect the nature and magnitude of gene action (through generation mean analysis) and heterosis and inbreeding depression under irrigated (two supplemental irrigations) and rainfed (on receding soil moisture) conditions. The experimental material comprised of five basic generations *viz.*, P_1, P_2, F_1, F_2 and F_3 of each of the five crosses of chickpea *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, laid out during *rabi*, 2004-05. The data were recorded on yield and its contributing characters namely, days to 50% flowering, days to maturity, plant height (cm), fruiting branches per plant, pods per plant, seeds per pod, biological yield per plant (g), seed yield per plant (g), harvest index (%), 100-seed weight (g) and protein content (%) under both the conditions. Salient findings are summarized as below:

1. The analysis of variance revealed significant differences among the crosses for all the characters under both irrigated and rainfed conditions. The generation mean sums of squares were significant in each of the five crosses for all the characters studied under both the conditions.

2. Pooled analysis of variance revealed that there were significant differences among environments (irrigated and rainfed) in all the crosses for all the characters studied except for seeds per pod in RSG-888 x ICC-4958 and BG-362 x RSG-931. The generation x environment interaction was also significant for most of the traits 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 RSG-931 and for protein content in RSG-895 x RSG-888 and RSG-888 x ICC-4958.

3. Comparison of mean values revealed that the mean values in all the five generations of each of the five crosses were, in general, lower under rainfed as compared to irrigated condition except for protein content (registered a slight increase) and for harvest index (no marked reduction was observed). The maximum reduction in the mean values under rainfed was observed for pods per plant, biological yield per plant, fruiting branches per plant and plant height. The detrimental effect of moisture stress in rainfed condition on seed yield was maximum through reduction in fruiting branches per plant, pods per plant, biological yield per plant and plant height. It was also revealed that bold seeded parents *viz.,* ICC-4958, BG-362 and IPC-94-94 and the crosses involving bold seeded parents had high mean values and were least affected by moisture stress in rainfed condition.

4. The individual scaling tests ‘C’ and ‘D’ revealed the presence of epistatic interactions in all the crosses for all the characters studied under both the conditions.

5. The application of joint scaling test (Cavalli, 1952) also confirmed the presence of epistatic interactions in all the five crosses for all the characters under both the conditions including pooled analysis over the environments.

6. Both main effects *i.e.*, additive (d) and dominance (h) were important for all the characters studied in all the crosses under both the conditions except for 100-seed weight, where only additive effect was important, with a greater magnitude of dominance than additive effect.

7. Among the digenic interactions, both additive x additive (i) and dominance x dominance (l) interactions were important with a greater magnitude of dominance x dominance (l) in all the crosses for all the characters under both the conditions except for 100-seed weight, where only additive x additive (i) interaction was found important.

8. The absolute totals of main effects and epistatic effects indicated that epistatic effects played greater role in controlling the inheritance of all the characters in most of the crosses under both the conditions in comparison to main effects.

9. The absolute totals of fixable and non-fixable gene effects revealed that non-additive gene effects played a greater role in controlling the inheritance of all the characters in all the crosses under both conditions including pooled analysis over environments except for 100-seed weight. Among the cases, where epistasis was established, duplicate type was most common.

10. Heterosis over mid parent was significant under both the conditions in most of the crosses for most of the characters except for seeds per pod. Similarly, significant heterobeltiosis were also observed for most of the traits in almost all the crosses under both the conditions except for fruiting branches per plant under rainfed condition. The range of heterobeltiosis was varied from -13.20 to 32.49 per cent in most of the characters. Inbreeding depression was also common in most of the cases. The components of heterosis revealed that (l) followed by (h) and (i) contributed maximum towards heterosis in all the characters under both the conditions. Absence of heterosis in most of the crosses could be explained on the basis of internal cancellation of heterotic components.

11. It was observed that the magnitude and signs of main effects and interaction effects differed among crosses frequently without any proper trend. These might be ascribed to narrow genetic base of parents and the expression of genes affected by the environments differently.

12. The choice of the cross should be made on the basis of *per se* performance, heterosis, inbreeding depression and type of gene action involved for the particular traits. On the basis of *per se* performance the desirable crosses are RSG-888 x ICC-4958, BG-362 x RSG-931 and IPC-94-94 x RSG-888 involving bold seeded parents (ICC-4958, BG-362 and IPC-94-94) were accompanied by significant positive heterosis over better parent in one or more of the yield components *viz.*, seed yield per plant, fruiting branches per plant, pods per plant, 100-seed weight, biological yield per plant and harvest index.

On the basis of above informations and results it was concluded that non-additive gene effects *viz.,* dominance (h) and dominance x dominance (l) controlled 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. The breeding methods suggested to achieve this objective are restricted recurrent selection, diallel selective mating (Jenson, 1970 and 1978), multiple crosses and bi-parental mating. The duplicate type of epistasis was also observed in all the characters in generation mean analysis, so the selection intensity should be mild in the earlier and intense in later generations.

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Table 4.1 Analysis of variance for different characters in chickpea crosses under irrigated (IRG) and rainfed (RF) conditions

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

	RF	0.005	0.689**	0.008

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

Table 4.3.13 Per cent decrease in the mean performance of different characters under rainfed condition as compared to irrigated condition

Characters	**Parents**	**F_1s**	**F_2s**	**F_3s**
Days to 50% flowering	4.74	9.80	9.94	8.26
Days to maturity	4.67	3.04	4.52	5.34
Plant height (cm)	8.43	7.74	9.77	10.99
Fruiting branches per plant	11.38	21.15	18.27	4.44
Pods per plant	22.97	18.02	14.43	9.74
Seeds per pod	0.95	0.63	0.44	0.42
Biological yield per plant (g)	13.23	14.69	14.26	9.19
Seed yield per plant (g)	16.10	12.62	11.41	12.21
Harvest index (%)	1.48	-1.66	0.04	-1.26
100-Seed weight (g)	3.98	4.11	3.39	5.24
Protein content (%)	-2.05	-0.65	-2.29	-3.12

Note:- Minus (-) indicates that there was slight increase in the mean values of these characters

APPENDIX – I

Weekwise details of temperature and rainfall during *rabi*, 2004-05

Meteorological week	Temperature		Rainfall (mm)	No. of rainy days
	Maximum (^{0}C)	Minimum (^{0}C)		
36	39.0	24.1	0.0	-
37	38.5	25.1	0.0	-
38	35.9	24.6	0.0	-
39	37.4	23.1	3.6	1
40	31.7	21.0	7.8	1
41	32.4	20.3	0.0	-
42	29.8	15.5	0.0	-
43	29.1	14.7	0.0	-
44	27.2	12.6	2.2	1
45	30.6	9.0	0.0	-
46	32.2	12.8	0.0	-
47	31.4	12.4	0.0	-
48	26.9	13.3	0.0	-
49	24.6	8.3	0.0	-
50	24.6	5.6	0.0	-
51	26.5	6.7	0.0	-
52	15.4	4.8	0.0	-
1	17.4	6.0	21.0	1
2	20.0	5.5	0.0	-
3	19.2	5.6	0.0	-
4	16.9	5.9	2.0	1
5	19.4	3.8	0.0	-
6	20.0	12.7	29.3	4
7	19.0	12.0	3.0	1
8	21.0	5.1	0.0	-
9	23.8	13.1	3.6	1
10	26.6	14.7	0.0	-
11	32.0	16.8	0.0	-
12	27.8	15.7	16.6	2
13	32.0	12.7	0.0	-
14	37.4	16.5	0.0	-
15	33.7	14.4	0.0	-
16	39.3	15.7	0.0	-
17	36.7	20.2	2.4	2

APPENDIX–II

The procedure for the estimation of Nitrogen content

(Snell and Snell, 1949)

Colorimetric method

Reagents used

i. Sulphuric acid (concentrated)

ii. Hydrogen peroxide 30%

iii. Nessler's reagent

Took 45.5 g of mercuric iodide and 35.0 g of potassium iodide, dissolved these two in 70.0 ml of distilled water, this was called solution A. In another beaker, dissolved 112.0 gm of NaOH in about 100 ml of distilled water, this was called solution B. Then, mixed solution A and B in a volumetric flask of 500 ml and made the volume. This mixed solution was kept over night and transferred the supernatant liquid in a coloured bottle and kept it in a dark place. This was called stock solution. The working solution was prepared from stock solution by taking stock solution and dissolving 4 times at the time of working.

iv. Sodium silicate 10% solution

Dissolved 10.0 gm of sodium silicate in 100 ml of warmed water and boiled for complete dissolution.

v. Sodium hydroxide 10% solution

Dissolved 10.0 g of NaOH pellets in 100 ml of distilled water.

Procedure for digestion and nitrogen determination:

0.1 g of dried and grinded grain sample was taken in 100 ml microkjeldahl flask, about 2.0 ml of concentrated H_2SO_4 was added slowly and heated gently on the hot plate [digestion assembly] till the sample was broken down and particles were dissolved. Flask was cooled and 0.5 ml of 30 % H_2O_2 was added and heated again, repeated the process till the solution became perfectly clear and colourless. Flask was cooled again and volume was made up.

5.0 ml of digested material [aliquot] was transferred in to 50 ml volumetric flask. Some water, 2 ml of 10 % NaOH and 1 ml of 10% sodium silicate was added and stirred well. There after, added 1.6 ml of diluted

working solution of Nessler's reagent, mixed thoroughly and the volume was made up to 50 ml. The colour intensity was read at 420 nm using Spectronic - 20.

Preparation of standard curve

Dissolved 0.1179 g of ammonium sulphate [Analytical Reagent Grade-I] in water and made the volume 1.0 litre in volumetric flask, this solution contained 25 ppm of nitrogen. Now from this solution, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and to 4.0 ml was taken in cubate and absorbance was measured at 420 nm. Observations were plotted on a graph *i.e.* concentration of N on X-axis and absorbance on Y-axis.

Observation and calculation

1. Weight of plant sample = 0.1 g
2. Volume of digested material = 100 ml
3. Volume of extract taken = 5 ml
4. Final volume prepared = 50 ml

Dilution factor = 100/0.1 x 50/5=10,000
Concentration of N in ppm = ppm N from standard curve (R) x 10,000
% N in plant sample = R x Dilution factor/10,000
Percentage of crude protein content = % N x 6.25 (A.O.A.C,1990)

Table: 4.2 Individual and pooled analysis of variance (mean squares) of generation means for different characters in five crosses of chickpea grown under irrigated (IRG) and rainfed (RF) conditions

Environment	IRG			RF			Pooled analysis of variance				
Source / Cross/Character	Rep. (2 df)	Gener. (4 df)	Error (8 df)	Rep. (2 df)	Gener. (4 df)	Error (8 df)	Rep./ Env. (4 df)	Gener. (4 df)	Env. (1 df)	G x E (4 df)	Error (16 df)
Days to 50% flowering											
RSG-895 x RSG-888	1.445	18.681**	2.090	0.002	7.390**	0.916	0.722	9.586**	412.799**	16.483**	1.504
RSG-888 x ICC-4958	0.048	12.398**	1.176	0.269	12.164**	1.016	0.159	20.624**	208.086**	3.938*	1.096
IPC-94-94 x RSG-888	0.064	319.744**	3.233	0.868	242.273**	3.534	0.466	428.814**	1320.254**	133.202**	3.384
CSJD-901 x RSG-931	0.452	4.144*	0.850	0.200	7.599**	0.783	0.326	7.858**	265.083**	3.885*	0.816
BG-362 x RSG-931	0.266	8.126**	0.850	0.464	22.468**	0.633	0.366	26.680**	40.756**	3.913**	0.741
Days to maturity											
RSG-895 x RSG-888	1.364	11.592*	1.947	0.171	16.669**	0.640	0.766	20.391**	418.133**	7.868**	1.294
RSG-888 x ICC-4958	2.561	24.823**	0.779	0.061	17.013**	0.907	1.312	30.251**	172.400**	11.586**	0.843
IPC-94-94 x RSG-888	2.399	250.044**	13.900	0.198	277.193**	3.117	1.300	494.347**	580.800**	32.892*	8.508
CSJD-901 x RSG-931	0.598	12.766**	0.766	0.468	15.235**	0.968	0.533	22.371**	224.079**	5.630**	0.867
BG-362 x RSG-931	0.268	33.388**	1.682	0.599	18.073**	1.684	0.434	32.991**	73.299**	18.471**	1.683

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

Contd…

Environment	IRG			RF			Pooled analysis of variance				
Source / Cross/Character	Rep. (2 df)	Gener. (4 df)	Error (8 df)	Rep. (2 df)	Gener. (4 df)	Error (8 df)	Rep./ Env. (4 df)	Gener. (4 df)	Env. (1 df)	G x E (4 df)	Error (16 df)
Plant height (cm)											
RSG-895 x RSG-888	0.001	40.021**	1.637	0.242	13.272*	2.379	0.121	41.525**	337.234**	11.768**	2.008
RSG-888 x ICC-4958	1.081	37.791**	4.305	2.539	15.087**	2.051	1.812	24.789**	250.377**	28.089**	3.178
IPC-94-94 x RSG-888	0.839	54.150**	5.200	1.032	53.350**	3.422	0.936	86.982**	43.056**	20.519*	4.311
CSJD-901 x RSG-931	5.069	40.133**	3.348	0.945	18.129**	1.731	3.006	36.605**	121.874**	21.657**	2.540
BG-362 x RSG-931	2.281	28.138**	3.591	0.611	55.511**	6.429	1.446	59.894**	318.220**	23.755*	5.010
Fruiting branches per plant											
RSG-895 x RSG-888	0.132	16.421**	0.788	0.997	7.565**	0.765	0.565	17.083**	137.217**	6.903**	0.776
RSG-888 x ICC-4958	1.391	18.542**	1.623	0.572	6.489**	0.524	0.983	18.536**	27.950**	6.496**	1.073
IPC-94-94 x RSG-888	0.640	25.117**	1.067	0.500	12.694**	0.915	0.570	24.441**	24.300**	13.369**	0.991
CSJD-901 x RSG-931	2.464	20.678**	0.730	0.162	5.592**	0.745	1.311	22.873**	19.976**	3.395*	0.738
BG-362 x RSG-931	0.098	17.179**	0.628	0.098	6.805**	0.254	0.099	19.045**	11.371**	4.941**	0.441

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

Contd…

Environment	IRG			RF			Pooled analysis of variance				
Source / Cross/Character	Rep. (2 df)	Gener. (4 df)	Error (8 df)	Rep. (2 df)	Gener. (4 df)	Error (8 df)	Rep./ Env (4 df)	Gener. (4 df)	Env. (1 df)	G x E (4 df)	Error (16 df)
Pods per plant											
RSG-895 x RSG-888	13.089	331.556**	16.370	1.237	173.984**	3.208	7.163	419.413**	973.674**	86.127**	9.789
RSG-888 x ICC-4958	1.798	142.749**	12.227	4.862	263.506**	3.416	3.330	341.484**	650.164**	64.771**	7.821
IPC-94-94 x RSG-888	3.174	151.826**	9.067	1.335	152.074**	6.353	2.256	251.215**	635.904**	52.686**	7.710
CSJD-901 x RSG-931	9.204	115.315**	14.863	7.074	177.750**	6.860	8.139	224.393**	1152.828**	68.672**	10.861
BG-362 x RSG-931	3.725	127.541**	10.562	1.866	147.495**	7.105	2.795	231.613**	555.212**	43.422**	8.834
Seeds per pod											
RSG-895 x RSG-888	0.016	0.041*	0.008	0.006	0.034**	0.004	0.011	0.071**	0.033*	0.004	0.006
RSG-888 x ICC-4958	0.002	0.078**	0.011	0.007	0.076**	0.004	0.004	0.150**	0.033	0.003	0.007
IPC-94-94 x RSG-888	0.003	0.043*	0.008	0.003	0.045**	0.001	0.001	0.069**	0.039*	0.016*	0.005
CSJD-901 x RSG-931	0.011	0.064**	0.009	0.001	0.019**	0.001	0.006	0.066**	0.035*	0.015*	0.005
BG-362 x RSG-931	0.003	0.024**	0.003	0.003	0.039**	0.003	0.001	0.057**	0.017	0.004	0.004

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

Contd…

Environment	IRG			RF			Pooled analysis of variance				
Source / Cross/Character	Rep. (2 df)	Gener. (4 df)	Error (8 df)	Rep. (2 df)	Gener. (4 df)	Error (8 df)	REP./ ENV (4 df)	Gener. (4 df)	Env. (1 df)	G x E (4 df)	Error (16 df)
Biological yield per plant (g)											
RSG-895 x RSG-888	2.423	45.621**	2.995	1.991	31.965**	2.133	2.206	60.081**	191.572**	17.504**	2.564
RSG-888 x ICC-4958	0.992	68.477**	2.640	0.879	81.273**	1.912	0.936	111.629**	385.137**	38.121**	2.276
IPC-94-94 x RSG-888	0.084	50.796**	2.072	1.487	33.537**	2.784	0.787	54.584**	140.078**	29.749**	2.428
CSJD-901 x RSG-931	3.787	28.793*	4.187	0.917	30.259**	1.191	2.351	30.553**	358.111**	28.498**	2.689
BG-362 x RSG-931	0.904	76.659**	4.451	2.529	38.431**	2.148	1.716	90.519**	68.675**	24.570**	3.300
Seed yield per plant (g)											
RSG-895 x RSG-888	0.588	20.359**	1.200	1.666	15.436**	0.738	1.125	25.269**	172.777**	10.524**	0.970
RSG-888 x ICC-4958	0.117	27.273**	1.123	1.336	41.168**	0.885	0.726	62.193**	23.870**	6.248**	1.004
IPC-94-94 x RSG-888	0.722	12.402**	1.194	0.578	19.553**	0.762	0.650	16.413**	9.509**	15.542**	0.978
CSJD-901 x RSG-931	1.274	10.832**	0.867	0.989	6.320**	0.345	1.132	14.272**	62.400**	2.879*	0.606
BG-362 x RSG-931	0.566	25.112**	1.242	0.259	30.401**	1.415	0.414	51.234**	19.018**	4.280*	1.328

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

Contd…

Environment	IRG			RF			Pooled analysis of variance				
Source / Cross/Character	Rep. (2 df)	Gener. (4 df)	Error (8 df)	Rep. (2 df)	Gener. (4 df)	Error (8 d.f.)	Rep./Env. (4 df)	Gener. (4 df)	Env. (1 df)	G x E (4 df)	Error (16 df)
Harvest index (%)											
RSG-895 x RSG-888	10.479	67.467**	5.798	1.283	66.859**	3.276	5.879	96.939**	231.778**	37.386**	4.537
RSG-888 x ICC-4958	1.297	77.514**	1.359	1.807	71.264**	1.842	1.553	123.058**	29.489**	25.721**	1.600
IPC-94-94 x RSG-888	0.629	28.351**	1.514	0.591	62.157**	1.106	0.609	48.440**	132.806**	42.067**	1.310
CSJD-901 x RSG-931	0.200	16.665*	2.504	0.258	13.102**	1.384	0.229	16.441**	30.724**	13.326**	1.944
BG-362 x RSG-931	0.682	37.732**	1.614	1.428	91.035**	1.379	1.054	107.491**	17.328**	21.276**	1.497
100-seed weight (g)											
RSG-895 x RSG-888	0.061	2.157**	0.094	0.326	1.972**	0.060	0.191	3.784**	1.152**	0.344*	0.077
RSG-888 x ICC-4958	1.256	75.130**	4.095	0.083	57.462**	0.503	0.669	131.818**	14.658*	0.774	2.299
IPC-94-94 x RSG-888	0.310	39.523**	2.176	1.515	28.635**	1.011	0.912	67.174**	8.175*	0.984	1.593
CSJD-901 x RSG-931	0.127	2.588**	0.144	0.163	3.884*	0.643	0.144	4.718**	4.074**	1.753*	0.394
BG-362 x RSG-931	0.461	44.749**	0.939	1.362	34.737**	0.654	0.913	78.924**	3.931*	0.563	0.796

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

Contd…

Environment	IRG			RF			Pooled analysis of variance				
Source / Cross/Character	Rep. (2 df)	Gener. (4 df)	Error (8 df)	Rep. (2 df)	Gener. (4 df)	Error (8 d.f.)	Rep./Env. (4 df)	Gener. (4 df)	Env. (1 df)	G x E (4 df)	Error (16 df)
Protein content (%)											
RSG-895 x RSG-888	0.183	1.145*	0.202	0.064	0.946**	0.066	0.125	1.947**	1.298**	0.145	0.134
RSG-888 x ICC-4958	0.055	1.929**	0.049	0.018	1.258**	0.041	0.035	3.075**	0.252*	0.111	0.045
IPC-94-94 x RSG-888	0.059	4.952**	0.094	0.055	3.812**	0.061	0.057	8.523**	0.666**	0.241*	0.078
CSJD-901 x RSG-931	0.193	2.515**	0.192	0.033	0.917**	0.027	0.113	2.610**	1.285**	0.823**	0.109
BG-362 x RSG-931	0.052	1.659**	0.191	0.019	0.132**	0.017	0.037	1.288**	2.191**	0.505**	0.104

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

Table 5.2 Summary table showing significant gene effects of five parameters model for different characters of chickpea grown under irrigated (IRG) and rainfed (RF) conditions.

Gene effects / Characters	(d)			(h)			(i)			(l)		
	IRG	**RF**	**Total**	**IRG**	**RF**	**Total**	**IRG**	**RF**	**Total**	**IRG**	**RF**	**Total**
Days to 50% flowering	5	5	10	5	4	9	3	5	8	4	5	9
Days to maturity	5	5	10	5	5	10	5	4	9	5	4	9
Plant height (cm	5	4	9	5	4	9	4	3	7	3	4	7
Fruiting branches per plant	5	4	9	5	5	10	3	4	7	4	5	9
Pods per plant	5	5	10	5	4	9	5	3	8	5	5	10
Seeds per pod	1	1	2	1	1	2	2	2	4	-	-	-
Biological yield per plant (g)	5	5	10	4	5	9	4	5	9	4	5	9
Seed yield per plant (g)	5	5	10	3	5	8	3	5	8	4	5	9
Harvest index (%)	3	5	8	4	4	8	4	4	8	3	5	8
100-Seed weight (g)	2	-	2	-	-	-	-	2	2	-	-	-
Protein content (%)	3	3	6	3	1	4	3	3	6	2	-	2
Total	**44**	**42**	**86**	**40**	**38**	**78**	**36**	**40**	**76**	**34**	**38**	**72**