# HETEROSIS AND $F_2$ GENETIC VARIABILITY IN SELECTED CROSSES FOR QUANTITATIVE TRAITS IN CHICKPEA (*Cicer arietinum* L.)

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**IN**

**GENETICS AND PLANT BREEDING**

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Affectionately dedicated to my beloved parents

Shri. Syed Mujeebur Rahman

Smt. Khutejatul Kubra

And

My Brother

Syed Riyazur Rahman

**DEPARTMENT OF GENETICS AND PLANT BREEDING**
**UNIVERSITY OF AGRICULTURAL SCIENCES**
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## CERTIFICATE

This is to certify that the thesis entitled **"HETEROSIS AND $F_2$ GENETIC VARIABILITY IN SELECTED CROSSES FOR QUANTITATIVE TRAITS IN CHICKPEA (*Cicer arietinum* L.)"** submitted in partial fulfillment of the requirements of **MASTER OF SCIENCE (Agriculture)** in **GENETICS AND PLANT BREEDING** to the University of Agricultural Sciences, Bengaluru is a bonafide record of research work carried out by **Ms. NOOR E MUJJASSIM, ID. No. PALB 4213,** during the period of her study in this University, under my guidance and supervision and no part of the thesis has been submitted for the award of any other degree, diploma, associateship, fellowship or any other similar titles.

BENGALURU
JULY, 2016

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**Major Advisor** 20/7/16

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**(M. SAIFULLA)**

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*July, 2016* ***(Noor E Mujjassim)***

# HETEROSIS AND $F_2$ GENETIC VARIABILITY IN SELECTED CROSSES FOR QUANTITATIVE TRAITS IN CHICKPEA (*Cicer arietinum* L.)

**NOOR E MUJJASSIM**

## ABSTRACT

An investigation was carried out to evaluate nine hybrids including three lines, three testers along with one check (JG 11) developed through L × T mating design at UAS, GKVK, Bengaluru, during *kharif* 2015 to assess general combining ability (gca) of parents, specific combining ability (sca) and heterosis of crosses, genetic variability of $F_2$ population and to explore interrelationship among the seed yield and its component traits. JAKI 9218 and JG 11 among lines seemed to possess additive and increasing genetic effects with respect to days to 50% flowering, plant height, seed yield plant$^{-1}$, 100 seed weight, days to maturity and JG 24 among the testers manifested significant gca effects for days to 50% flowering, seed yield plant$^{-1}$, 100 seed weight and days to maturity. Among crosses, JAKI 9218 × JG 315 exhibited higher sca effect for four yield attributing traits. Lines *viz*., A-1, JG 11 and tester JG 24 were good general combiners. Phenotypic correlation coefficient depicted seed yield plant$^{-1}$ had significant positive correlation with plant height and number of pods plant$^{-1}$ in crosses *viz*., A-1 × JG 315, A-1 × HC 5, JG 11 × JG 24 and JAKI 9218 × HC 5. Higher estimates of phenotypic coefficient of variation (PCV) were observed for number of primary branches, number of pods plant$^{-1}$ and seed yield plant$^{-1}$ in all the four crosses *viz*., JAKI 9218 × HC 5, A-1 × JG 315, A-1 × HC 5 and JG 11 × JG 24, of $F_2$ population.

JULY, 2016 **(S. D. NEHRU)**
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# ಕಡಲೆಯಲ್ಲಿ ಆಯ್ಕೆಮಾಡಿದ ಸಂಕರಣಗಳ ಉತ್ತರಿವರ್ತತೆ ಮತ್ತು ಎಫ್೨ ಅನುವಂಶೀಯ ವ್ಯತ್ಯಾಸ ನಿಯತೆಯ ಪರಿಮಾಣಾತ್ಮಕ ಲಕ್ಷಣಗಳ ವಿಶ್ಲೇಷಣೆ

**ನೂರ್ ಇ ಮುಜ್ಞಾಸಿಮ್**

**ಪ್ರಬಂಧ ಸಾರಾಂಶ**

ಜನ್ಮದಾತುಗಳ ಸಾಮಾನ್ಯ ಸಂಯೋಜಕ ಸಾಮರ್ಥ್ಯವನ್ನು ಮತ್ತು ಸಂಕರಣಗಳ ನಿರ್ದಿಷ್ಟ ಸಂಯೋಜಕ ಸಾಮರ್ಥ್ಯ ಹಾಗೂ ಸಂಕರಣ ಒಜದ ಸಾಪೇಕ್ಷಮಾನವನ್ನು ವಿಮರ್ಶಿಸಲು, ಅನುವಂಶಿಕ ವ್ಯತ್ಯಾಸ ಮತ್ತು ಎಫ್೨ ಜನಸಂಖ್ಯೆಯಲ್ಲಿನ ಪರಸ್ಪರ ಬೀಜ ಇಳುವರಿ ಮತ್ತು ಲಕ್ಷಣಗಳ ಅನ್ವೇಷಣೆಗೋಸ್ಕರ ಒಂದು ಅಧ್ಯಯನವನ್ನು ಕೈಗೊಳ್ಳಲಾಯಿತು. ಮೂರು ಪೋಷಕ ತಳಿಗಳು, ಮೂರು ಪರೀಕ್ಷಕ ತಳಿಗಳು, ಒಂಭತ್ತು ಸಂಕರಣ ತಳಿಗಳ ಜೊತೆಗೆ ಒಂದು ಬಳಕೆಯಲ್ಲಿರುವ ತಳಿಗಳೊಂದಿಗೆ ಅಭಿವೃದ್ಧಿ ಪಡಿಸಿದ ಸಾಲು X ಪರೀಕ್ಷಕ ಮಿಲನದ ವಿನ್ಯಾಸದಲ್ಲಿ, ಮುಂಗಾರು ಋತುವಿನಲ್ಲಿ ಕೃಷಿ ವಿಶ್ವವಿದ್ಯಾನಿಲಯ, ಗಾ.ಕೃ.ವಿ.ಕೇ., ಬೆಂಗಳೂರಿನಲ್ಲಿ ಅಧ್ಯಯನ ಮಾಡಲಾಯಿತು. ಪೋಷಕ ತಳಿಗಳಾದ ಜೆ.ಎ.ಕೆ.ಐ.- ೯೨೧೮ ಮತ್ತು ಜೆ.ಜಿ.-೧೧ ರಲ್ಲಿ ಸರಾಸರಿ ಶೇಕಡ ೫೦ ಹೂಬಿಡುವ ದಿನಗಳು, ಸಸ್ಯದ ಎತ್ತರ, ಸಸ್ಯದ ಪ್ರತಿ ಬೀಜ ಇಳುವರಿ, ೧೦೦ ಬೀಜ ತೂಕ, ಮುಕ್ತಾಯ ದಿನಗಳು ಹಾಗೂ ಪರೀಕ್ಷಕ ತಳಿ ಜೆ.ಜಿ.-೨೪ ರಲ್ಲಿ, ನಾಲ್ಕು ಉತ್ಪಾದನೆಯ ಲಕ್ಷಣಗಳಾದ ಶೇಕಡ ೫೦ರಷ್ಟು ಹೂಬಿಡುವ ದಿನಗಳು, ಸಸ್ಯದ ಪ್ರತಿ ಬೀಜ ಇಳುವರಿ, ೧೦೦ ಬೀಜ ತೂಕ ಮುಕ್ತಾಯ ದಿನಗಳು, ಸಂಕಲಿತ ಮತ್ತು ಅಧಿಕ ವಂಶವಾಹಿ ಪರಿಣಾಮಗಳನ್ನು ತೋರ್ಪಡಿಸಿತು. ಜೆ.ಎ.ಕೆ.ಐ.- ೯೨೧೮, ಜೆ.ಜಿ.- ೩೧೫ ಸಂಕರಣವು ಹೆಚ್ಚಿನ ನಿರ್ದಿಷ್ಟ ಸಂಯೋಜಕವಾಗಿ ಕಂಡುಬಂದಿತು. ಪೋಷಕ ತಳಿಗಳಲ್ಲಿ ಎ-೧ ಹಾಗೂ ಜೆ.ಜಿ.-೧೧ ಮತ್ತು ಪರೀಕ್ಷಕ ತಳಿಗಳಲ್ಲಿ ಜೆ.ಜಿ.-೨೪ ಹೆಚ್ಚಿನ ಸಾಮಾನ್ಯ ಸಂಯೋಜಕಗಳಾಗಿ ಕಂಡುಬಂದವು. ಸಂಕರಣಗಳಲ್ಲಿ ಎ-೧ X ಜೆ.ಜಿ.- ೩೧೫, ಎ-೧ X ಹೆಚ್.ಸಿ- ೫, ಜೆ.ಜಿ.- ೧೧ X ಜೆ.ಜಿ.- ೨೪, ಜೆ.ಎ.ಕೆ.ಐ.- ೯೨೧೮ X ಹೆಚ್.ಸಿ- ೫ ಚಿತ್ರಿಸಲಾದ ಬಾಹ್ಯ ಪರಸ್ಪರ ಸಂಬಂಧ ಗುಣಾಂಕ, ಸಸ್ಯದ ಪ್ರತಿ ಬೀಜ ಇಳುವರಿಯು, ಸಸ್ಯದ ಎತ್ತರ ಹಾಗೂ ಸಸ್ಯದ ಪ್ರತಿ ಬೀಜಕೋಶಗಳ ಸಂಖ್ಯೆ ಜೊತೆಗೆ ಗಮನಾರ್ಹ ಸಕಾರಾತ್ಮಕ ಸಂಬಂಧ ಹೊಂದಿದೆ. ಎಫ್೨ ಜನಸಂಖ್ಯೆಯ ನಾಲ್ಕು ಸಂಕರಣಗಳಾದ ಜೆ.ಎ.ಕೆ.ಐ.- ೯೨೧೮ X ಹೆಚ್.ಸಿ- ೫, ಎ-೧ X ಜೆ.ಜಿ.-೩೧೫, ಎ-೧ ಜೆ.ಜಿ.- ೩೧೫, ಎ-೧ X ಹೆಚ್.ಸಿ-೫ ಮತ್ತು ಜೆ.ಜಿ.-೧೧ X ಜೆ.ಜಿ.-೨೪ ಗಳಲ್ಲಿ ಪ್ರಾಥಮಿಕ ಶಾಖೆಗಳ ಸಂಖ್ಯೆ, ಸಸ್ಯದ ಪ್ರತಿ ಬೀಜಕೋಶಗಳ ಸಂಖ್ಯೆ ಹಾಗೂ ಸಸ್ಯದ ಪ್ರತಿ ಬೀಜ ಇಳುವರಿಗಳಲ್ಲಿ ಹೆಚ್ಚಿನ ಬಾಹ್ಯ ಗುಣಾಂಕ ವ್ಯತ್ಯಾಸವನ್ನು ಗಮನಿಸಲಾಯಿತು.

ಜುಲೈ, ೨೦೧೬ (ಎಸ್. ಡಿ. ನೆಹರು)
ಅನುವಂಶೀಯತೆ ಮತ್ತು ಸಸ್ಯ ತಳಿ ಅಭಿವೃದ್ಧಿ ವಿಭಾಗ, ಪ್ರಧಾನ ಸಲಹೆಗಾರರು.
ಕೃಷಿ ವಿಶ್ವವಿದ್ಯಾನಿಲಯ, ಗಾ.ಕೃ.ವಿ.ಕೇ., ಬೆಂಗಳೂರು.

# Study of Heterosis and Combining ability in selected crosses for Quantitative traits in Chickpea (*Cicer arietinum* L.).

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## Introduction

- Chickpea is a self-pollinated, annual, diploid (2x = 2n = 16), cool season food legume.
- To know the potential of hybrids in a crop, the study of the magnitude and direction of heterosis is of paramount importance.
- Estimation of heterosis will help in identifying genetically potential crosses for further exploitation in first generation itself.
- The study of combining ability helps in isolating useful parental lines and desirable specific cross combinations which could be further exploited in development of improved varieties.
- Accordingly, the present study was undertaken to have the knowledge on nature of combining ability and heterosis for yield and yield attributes in chickpea.

## Objectives

- To assess heterosis of crosses for yield and its attributes.
- To assess parental general combining ability and specific combining ability of crosses .

## Material and methods

- The experimental material consist of 3 females (A-1 ,JG 11,JAKI 9218) and 3 males ( JG -24, HC-5 and JG 315 ).
- During Rabi-summer 2014-15 crossing is done in Line × Tester mating design.
- During early kharif 2015 9F1's are evaluated for quantitative traits along with parents and standard check (JG–11) in RCBD design with two replications.
- Five randomly sampled plants in each cross were chosen for recording observations on quantitative traits.

STATISTICAL ANALYSIS:

- Trait means of 5 randomly sampled plants were used for biometrical genetic analysis.
- General combining ability of lines and testers, specific combining ability and heterosis of crosses were estimated using line × tester design.

## Experimental results

Analysis of variance for combining ability of yield and its attributing traits in parents and hybids of Chickpea.

| Source of Variations | df | Mean sum of squares | | | | |
|---|---|---|---|---|---|---|
| | | Days to 50% flowering | Plant height | Seed yield plant$^{-1}$ | 100 seed weight | Days to maturity |
| Replicates | 1 | 0.83 | 1.83 | 325.64 | 1.58 | 0.53 |
| Treatments | 14 | 21.77** | 61.57** | 44.36** | 45.8** | 31.39** |
| Parents | 5 | 45.283** | 61.03** | 8.37 | 91.57** | 32.00** |
| Parents (Line) | 2 | 66.66** | 57.97* | 15.12 | 36.62** | 52.66** |
| Parents(Testers) | 2 | 28.16** | 68.98** | 4.93 | 189.01** | 16.66 |
| Parents (L vs T) | 1 | 36.75** | 51.25* | 1.74 | 6.60* | 21.33 |
| Parent vs Crosses | 1 | 54.45** | 467.97** | 272.86** | 10.90* | 91.02** |
| Crosses | 8 | 3.0* | 11.10 | 38.29* | 21.55** | 23.55** |
| Line effect | 2 | 4.16 | 35.51** | 16.12** | 5.04 | 61.55** |
| Tester effect | 2 | 5.16** | 6.32 | 70.24 | 65.37* | 10.88** |
| Line * Tester effect | 4 | 1.33 | 1.29 | 33.40** | 7.90** | 10.88** |
| Error | 14 | 0.83 | 9.43 | 11.22 | 1.36 | 4.81 |

Table 2. Estimates of specific combining ability effects of hybrids for yield and its attributing traits in Chickpea.

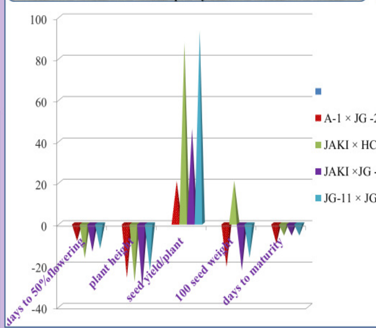
| Hybrids | Days to 50% flowering | Plant height (cm) | Seed yield plant$^{-1}$ (g) | 100 seed weight (g) | Days to maturity |
|---|---|---|---|---|---|
| JAKI × JG - 315 | - 0.83 | - 0.16 | 0.54 | 2.12* | -1.55** |
| JG-11 × JG - 315 | 0.33 | - 0.47 | - 4.90 | - 2.19* | 3.11** |
| S.Em.± | 0.60 | 2.00 | 2.45 | 0.87 | 0.00 |
| C.D @ P= 0.05 | 1.38 | 4.63 | 5.65 | 2.01 | 0.00 |

Table 3. Estimates of general combining ability effects of lines and testers for yield and its attributing traits in Chickpea.

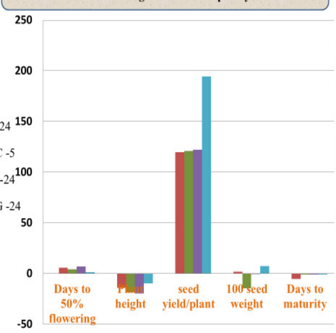
| PARENTS | DAYS TO 50% FLOWERING | PLANT HEIGHT ( cm) | SEED YIELD PLANT$^{-1}$ (g) | 100 SEED WEIGHT (g) |
|---|---|---|---|---|
| JG 11 | -0.83* | 1.54** | 1.87** | 0.46 |
| JG - 315 | 0.16 | -0.90 | -3.90* | -2.70** |
| JG 24 | 0.83* | -0.21 | 2.49** | 3.67** |
| S.Em.± | 0.34 | 1.15 | 1.41 | 0.50 |
| C.D @ P= 0.05 | 0.80 | 2.67 | 3.26 | 1.16 |

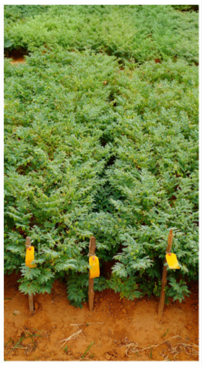
- ✓ The line JG 11 and the testers JG 315, JG 24 registered high general combining ability effects for days to 50% flowering, plant height, seed yield plant$^{-1}$ and test weight ( table 3 ).
- ✓ The crosses JAKI × JG 315 and JG 11 × JG 315 expressed significant specific combining ability for test weight and days to maturity ( table 2 ).
- ✓ JG 11 × JG 24 shows high better parent and standard heterosis for seed yield plant$^{-1}$ .

1. Estimates of Better parent heterosis for grain yield and its attributing traits in Chickpea hybrids




2. Estimates of standard heterosis over JG – 11 for grain yield and its attributing traits in Chickpea hybrids



## Discussion

- ✓ Highly significant differences among crosses could be due to differences in both lines , testers and line × tester interaction.
- ✓ The magnitude and direction of gca effects varied with lines and testers as well as with the traits, indicating differential ability of lines and testers to transmit additive genes to the progeny.
- ✓ No single line or testers was a good general combiner for all traits.
- ✓ Different cross combinations expressed significant sca effects in desirable direction for different characters.
- ✓ Significant heterosis over better parent is observed in majority of crosses for any traits It indicates involvement of non – additive gene action in the genetic control of that trait.

## Summary

- Study indicated that JG 24 is a good general Combiner for selected productivity traits in Chickpea.
- The cross JG 11 × JG 24 was identified as a desirable specific combiner for selected productivity traits in chickpea.

## Reference

BHARDWAJ, J. S., SANDHU AND INDERJIT SINGH., 2010, Heterosis in relation to combining ability in chickpea (*Cicer arietinum* L.). *Crop improv.*, **37** (2): 126-132.

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# I INTRODUCTION

Chickpea (*Cicer arietinum* L.) is a self-pollinated, annual, diploid (2x = 2n= 16), cool season food legume. An ancient crop, is important in both developed and developing nations. It originated in south-eastern Turkey and the adjoining northern region of Syria. Wild progenitor *C. reticulatum* and its other closely related wild species *C. echinospermum* and *C. bijugum*. The genus *Cicer* includes 43 species, nine of which are annual.

About 80 *per cent* of the chickpea area is under the Desi type and the remaining area under the Kabuli type. Chickpea is grown mainly in the Indian subcontinent, West Asia, North and East Africa, southern Europe, and South and Central America. Chickpea is the third most important legume globally, after common bean and pea and it is valued as source of protein to the largely vegetarian population of India.

In India, chickpea accounts for about 45 *per cent* of total pulses produced in the country. Similar to the case of other pulses, India is the major producing country for chickpea, contributing for over 75 *per cent* of total production in the world. More than two-third (67 *per cent*) of the total chickpea area in the country lies in central and southern India (Madhya Pradesh, Maharashtra, Andhra Pradesh and Karnataka). In India Chickpea covers an area of 9.21 m. ha with annual production of 8.88 m. t and productivity 995 kg/ha (India stat.com., 2013). In Karnataka the crop is grown on an area of 8.0 lakh ha with a production of 3.80 lakh t and productivity is 473 kg/ha (India stat.com., 2013).

Chickpea is a highly self-pollinated crop and the scope for exploitation of hybrid vigour is considered to be one of the outsanding achievements of plant breeding. Though it has played an important role in allogamous crops, heterosis has been used only in a few autogamous crops. To know the potential of hybrids in a crop, the study on magnitude and direction of heterosis is of paramount important. Heterotic response being dependent upon the degree of genetic divergence among the parents involved and it would be of great interest to know the extent of heterosis among divergent types in chickpea.

Variability, which is the genetic base of a crop and is the basic requirement for making progress in crop breeding. Therefore, in any breeding programme inclusion of genetically diverse parents is essential in order to create new reservoirs of genetic variability which in turn would helps in recombination of genes from diverse sources. In different crosses involving diverse parents, it is important to know the relationship between parents and heterosis in their hybrids.

Breeders have been utilizing the available genetic resources to modify the varieties to meet the ever changing requirements. However, in self pollinated crop, the heterosis can not be exploited directly, hybrid vigour identify superior hybrids as they offer more probability of throwing better segregants (Afsari Sharif *et al.*, 2001). In chickpea beneficial heterosis for grain filling period, seeds per plant and grain yield was reported by Ahmed Bakhsh *et al.* (2007).

The present study was designed to estimate the degree of hybrid vigor, extent of heritability and genetic advance in $F_1$ hybrids. The information obtained could be used to select superior segregants from better hybrids for stress resistance, better adaptability. From last two decades it is realized that yield of chickpea is stagnated. To break the yield platue hybrid breeding is one of the alternatives. But commercial hybrid seed production is not possible due to cleistogamous flower and unavailability of sterility gene in chickpea. Therefore, there is a need to develop new high yielding varieties through hybridization using diverse parents.

The study of combining ability helps in isolating useful parental lines and desirable specific cross combinations which could be further exploited in development of improved varieties. Estimation of heterosis will help in identifying genetically potential crosses for further exploitation in first generation itself. Accordingly, the present investigation was undertaken to have the knowledge on nature of combining ability and heterosis for yield and yield attributes in chickpea for developing new varieties. The exposer of the crop to higher temperature during late phase of maturity adversely affects the seed yield of the crop under late sowing (November or December). To overcome these difficulties, it is necessary to develop varieties which can mature within 90 days and also give better yield. Thus a negative heterosis for days to 50 *per cent* flowering and maturity is desirable in chickpea productivity.

Of late, to circumvent the problem of labour shortage, breeding efforts are being made to develop varieties suitable for mechanical harvesting. The traits such as tall, erect stem and earliness are identified as suitable for mechanical harvesting. In view of this, the objectives for the present investigation is planned and are presented below;

1. To estimate the heterosis for seed yield and its attributing traits.

2. To assess the genetic variability for seed yield and its components in $F_2$ population of selected crosses.

3. To explore interrelationship among the seed yield and its component traits in $F_2$ generations of selected crosses.

# II REVIEW OF LITERATURE

Chickpea is a highly self-pollinated crop and the scope for exploitation of hybrid vigour will depend on the direction and magnitude of heterosis, biological feasibility and the type of gene action involved. Also, study of heterosis and inbreeding depression will have a direct bearing on the breeding methodology to be employed for varietal improvement. The knowledge of heritability and genetic advance help to identify characters with potential improvement and to decide upon the selection pressure in breeding material.

The literature pertaining to the present investigation related to Chickpea is presented under the following headings.

2.1 Heterosis and combining ability

2.2 Genetic variability for yield and its components.

2.3 correlation and path co-efficient for yield and yield components.

**2.1 Heterosis and combining ability**

Heterosis is defined as increased vigour of the $F_1$ hybrids of a cross over the mean of the parent or over better parent. The literature on heterosis reported from and onwards have been reviewed and presented in the following paragraph.

Kunadia and Singh (1980) evaluated 28 $F_1$ hybrids from kabuli type of which only 5 hybrids exhibited high heterosis over the better parent for yield plant$^{-1}$. Hybrids with high heterosis for yield had positive and significant values for heterosis and heterobeltiosis for pod number plant$^{-1}$ and number of primary branches plant$^{-1}$. Most hybrids showing heterosis for yield and pod number plant$^{-1}$ in $F_1$ and exhibited high inbreeding depression for these characters in the $F_2$.

Deshmukh and Bhapkar (1982) reported that high heterosis for grain yield coupled with high heterosis for number of branches plant$^{-1}$, number of pods plant$^{-1}$ and biological yield. Extent of heterosis over better parent ranged from 27.28 *per cent* for grains pod$^{-1}$ (Selection- 436 x Chafa) to 111.31 *per cent* for pods per plant (Phule G-5 x Annegiri). In general, hybrids showing high heterosis also showed high inbreeding depression.

Mandal and Bahl (1984) studied three sets of crosses comprising 24 hybrids for manifestation of better parent heterosis for grain yield and seven other agronomic characters. Of the three types of crosses, Indian desi x kubuli, hybrids exhibited the highest average heterosis and wide range of heterotic effects for grain yield and some of its components. Indian desi x exotic desi crosses showed poor to average heterosis for most of the characters.

Tewari and Pandey (1987) observed in many crosses which have exhibited moderate to high manifestation of better parent heterosis for number of pods plant$^{-1}$, number of seeds plant$^{-1}$ and seed yield plant$^{-1}$. The estimates of heterosis for seeds pod$^{-1}$ and 100-seed weight were mostly negative. They reported that all the crosses showing maximum estimates of heterosis for seed yield also had significant heterotic effects for some of the yield component.

Studies on 28 chickpea populations comprising 7 parents and 21 hybrids by Mian and Bahl (1989) indicated relationship between divergence of the parents and heterosis in the hybrids and found that parental clusters separated by medium $D^2$ values exhibited significant and positive mid parental heterosis for seed yield and some of its components.

Bahl and Kumar (1989) evaluated 25 chickpea hybrids and reported that manifestation of heterosis was maximum for seed yield and minimum for 100 seed weight. High heterosis for trait was generally accompanied by significant inbreeding depression. The sca variance were greater than those for gca for yield and its components, except 100 seed weight where contribution of gca was greater .They suggested importance of non additive gene action in chickpea due to parallel relationship between heterosis and inbreeding depression.

Pandey and Tiwari (1989) studied five crosses and found no uniform trend in the manifestation of heterosis in all the crosses for different characters.Three crosses exhibit significant heterosis over better parent for number of pods plant$^{-1}$ , number of seeds plant$^{-1}$ and seed yield plant$^{-1}$. The maximum heterosis (29.02 *per cent* and 16.76 *per cent*) associated with maximum inbreeding depression for yield was noted in one cross.They reported that the low heterosis might be due to inter concellation of gene effects.

Rao and Chopra (1989) obtained high positive values for average heterosis and heterobeltiosis for seed yield, number of primary branches plant$^{-1}$ , number of secondary branches plant$^{-1}$, number of pods plant$^{-1}$ , number of seeds plant$^{-1}$ and seed weight.

Shinde and Deshmukh (1990) obtained maximum heterosis over better parent for number of pods plant$^{-1}$ (54.95 *per cent*) followed by the grain yield (53.69 per cent), number of' fruiting branches plant$^{-1}$ (46.92 *per cent*), number of grains pod$^{-1}$ (21.94 *per cent*), 100 seed weight (15.83 *per cent*) and days to maturity (11.26 *per cent*). The overall mean heterosis was the highest for the grain yield plant$^{-1}$ (25.25 *per cent*) and days to maturity (11.26 *per cent*) followed by the number of pods plant$^{-1}$ (23.96 *per cent*) and number of fruiting branches plant$^{-1}$ (21.30 *per cent*).

Kamatar *et al.* (1996) studied 66 crosses in chickpea and reported that maximum positive heterosis was observed for pod number (144.3 *per cent*) followed by grain yield plant$^{-1}$ (130.5 *per cent*), total number of branches plant$^{-1}$ (120.46 *per cent*). They reported heterosis for yield was mainly associated with heterosis for number of primary branches plant$^{-1}$, total number of branches plant$^{-1}$ and number of pods plant$^{-1}$.

Nine $F_1$'s of chickpea and their parents were evaluated in randomized complete block design to estimate heterosis and heritability of grain yield and yield components by Ahmed Bakhsh *et al.* (2007). Significant differences among genotypes were found in grain yield and seven other yield components. Heterosis over mid parent in primary and secondary branches ranged from 12.31 per cent to 56.82 per cent and from 11.19 *per cent* to 93.03 *per cent*, respectively. Heterotic effects for 100 seed weight, grain yield per plant and biological yield per plant varied from 18.78 *per cent* to 32.96 *per cent*, 4.05 *per cent* to128.49 *per cent* and 9.25 *per cent* to 116.82 *per cent*. Broad sense heritability for different traits ranged from 45.23 *per cent* to 85.76 *per cent*.

Studies on heterosis and combining ability of 30 $F_1$s under a drought-prone, rainfed short-duration environment (SDE) in a line ×tester design by Venkatraman *et al.* (2007) revealed that the GCA variances were significant and of a high magnitude, while specific combining ability (SCA) variances were non-significant. A large number of crosses showed positive mid-parent heterosis (MPH) and better-parent heterosis (BPH). The average mid-parent heerosis and better-parent heterosis for biological yield was 22.36 *per cent* and 12.65 *per cent*, respectively, and the average MPH and BPH for the harvest index was 2.22 *per cent* and 0.92 *per cent*, respectively.

Bhardwaj *et al.* (2010) in a study involving 6 x 6 diallel cross set for yield and its associated traits in chickpea. For major grain yield components, namely, number of pods plant$^{-1}$, number of seeds pod$^{-1}$, harvest index, 100-seed weight and shorter plant height, the heterosis observed was either due to good gca of the parents or due to high sca effect of the respective crosses.The results showed no direct association between the general combining abilities of the parents involved in the crosses and heterotic response. Choice of best cross combination on the basis of high sca or *per se* performance would not necessarily give high heterosis. The gca, sca and *per se* performance of the crosses should be given equal importance while selecting for heterotic combinations.

Dodiya *et al.* (2012) conducted an experiment to estimate heterosis for 11 yield and yield related traits revealed that, out of 15 hybrids, seven hybrids recorded significant positive heterosis for yield plant$^{-1}$, five and eleven hybrids recorded significant positive heterobeltiosis and economic heterosis for yield plant$^{-1}$, respectively. The cross KWR-l08 X DCP-923 showed the highest magnitude of heterosis and heterobeltiosis for yield per plant$^{-1}$, biological yield and 100 grain weight.

Chauhan *et al.* (2013) conducted studies on $F_1$ and $F_2$ progenies of a six parent diallel cross (excluding reciprocals) of chickpea were analyzed for heterosis, combining ability and inbreeding depression for quantitative and quality traits. They observed significant differences among the parents for general combining ability (gca) and crosses for specific combining ability (sca) for all the characters studied except number of grains per pod. Estimates of inbreeding depression revealed that six $F_2$'s showed significant negative inbreeding depression for grain yield.

In a diallel mating design involving six chickpea parents *viz*., KWR-108, IPC-94-19, DCP-92-3, IPC-97-72, IPC-94-94 and MPJG-2000-108 in diallel mating scheme was carried out to study heterosis and combining ability by Gadekar and Dodiya (2013). Among the parents, IPC-94-19, IPC-97-72 and MPJG-2000-108 were found to be the best general combiners for yield and most of its contributing characters. Cross IPC-94-19 x IPC-94-94 showed the highest significant positive economic heterosis for grain yield plant $^{-1}$, biological yield plant$^{-1}$ and number of pods plant$^{-1}$. Two crosses namely KWR-108 X DCP-92-3 and IPC-94-19 X DCP-92-3 found heterotic for grain yield and other component characters involved one parent as good combiner and these crosses would be useful for the production of superior transgressive segregants in advanced generations.

Neelu Mishra *et al*. (2013) studied 8 hybrid combinations and observed that the heterosis over best parent in various cross combinations for most of the traits besides desirable inbreeding depression in $F_2$ populations. Significant and positive heterosis over best parent with negative inbreeding depression was observed for grain yield in only one cross (DCP 92-3 x IPCK 2002-29).

Reddy Yamini *et al*. (2015) studied heterosis for yield and physiological attributes in chickpea utilising 21$F_1$'s and seven parents from a 7 x 7 diallel set of crosses. Crosses NBeG-3 x Vihar, JG-11 x Vihar and ICCV 05106 x Vihar exhibited significant heterosis for days to first flowering and days to maturity in desirable negative direction. JG-11 x ICCV 05106, JG-11 x KAK-2 and ICCV 05106 x Vihar recorded significantly higher *per se* performance for yield and yield attributes for number of branches plant$^{-1}$, number of pods plant$^{-1}$ and heterosis over mid parent and better parent.

**2.2 Genetic Variability for yield and its components.**

The assessment of quantitative variables for genotypic variance, estimates of heritability and genetic advance are important for successful selection programme to evolve promising cultivars.

Genetic variance is separated from total variances using the estimate of environmental variances in non-segregating population (Pawar, 1942). The heritable variation was further divided into additive and non-additive components and the later function included dominance and interallelic interaction (Fisher *et al*., 1932 ). If the heritable variation in the genes controlling a character is purely additive, then that character can be fixed by selection and maximum genetic advance can be accomplished by continuous selection ( Panse, 1957 ) .

Imtiyaz Ahmed Khan *et al*. (1989) studied the broad sense heritability,expected genetic advance,and dominance estimates for days to 50 *per cent* fowering, plant height, number of primary branches, number of pods plant$^{-1}$ , number of seeds plant$^{-1}$ , 100 seed weight and grain yield plant$^{-1}$ were studied in seven crosses of chickpea and reported that all the characters were quantitativily inherited with varying degrees.

Muhammad Arshad *et al.* (2004) revealed high heritability with low genetic advance for days to flowering, days to maturity and 100 seed weight and indicated the influence of dominant and epistatic genes for these traits. High heritability of secondary branches and biological yield coupled with high genetic advance revealed that additive gene effects are important in determining these characters.

Jeena *et al.* (2005) concluded that high amount of genetic variability was expressed by pods/plant, 100-seed weight, biological yield plant$^{-1}$ and seed yield plant$^{-1}$. These characters also exhibited high predicated genetic advance with high heritability.

studies on genetic variability between yield and yield components in 15 kabuli chickpea genotypes by Derya Ozveren Yucel *et al.* (2006) concluded that genotypic variance was the highest for 100 seed weight, followed by seed number plant$^{-1}$. Broad-sense heritability ranged from 5.47 *per cent* (days to flowering) to 51.66 *per cent* (seed number plant$^{-1}$). Heritability for seed number, 1000 seed weight, and number of full pods were greater than those for the other traits.

Meena *et al.* (2006) revealed that the magnitude of phenotypic coefficient of variation (PCV) was higher than the corresponding genotypic coefficient of variation (GCV) for all the characters suggesting the influence of environmental effects on the expression of these traits. The phenotypic and genotypic coefficients of variation were highest for 100-seed weight followed by seed yield whereas relative leaf water content and days to maturity (2.12 and 2.03) showed the low phenotypic coefficient of variation and genotypic coefficient of variation respectively.

Kanaka Durga *et al.* (2007) studied on genetic variability for yield and yield components in chickpea revealed maximum variability for branches plant$^{-1}$ followed by pods plant$^{-1}$ and seed yield. High heritability was noticed for days to 50 *per cent* flowering and test weight indicating that improvement is possible through direct selection in respect of these traits. High heritability coupled with high genetic advance observed for days to 50 *per cent* flowering, pods plant$^{-1}$ and seed yield indicate additive gene effects.

Vaghela *et al.* (2009) conducted an experiment to study the variability of characters in fifty diverse genotypes of kabuli chickpea. Analysis of variance revealed significant genotypic differences for all the ten characters with wide range of variations. Estimates of genotypic and phenotypic co-efficients of variation were high for seed yield plant$^{-1}$ and number of pods plant$^{-1}$. Broad sense heritability was higher for all the traits except plant height. High genetic advance expressed as a percentage of mean was exhibited by seed yield plant$^{-1}$ and number of pods plant$^{-1}$.

Jayalakshmi *et al.* (2011) evaluated 15 $F_2$ populations for genetic variability. Promising crosses for yield and yield contributing characters were ‘JG 11’ × ‘ICC 4958’, ‘JAKI 9218’ × ‘ICC 4958’ and ‘M. Dollar’ × ‘ICC 4958’ whereas, ‘KAK 2’ × ‘ICC 506 EB’ with high genotypic coefficient of variation and high heritability.

Lal Hussain Akhtar *et al*, (2011) studied genetic variability, heritability for seed yield and its components in 20 advanced genotypes of chickpea. Broad sense heritability ranged from 89.61 (seed yield) to 99.99 *per cent* (100-seed weight). Heritabilities for 100-seed weight and number of pods plant$^{-1}$ were the greatest compared to other traits. Phenotypic coefficient of variation for days to flowering, days to maturity, plant height and seed yield were higher than genotypic coefficient of variations indicating that the expression of these traits is more influenced by environmental effect.

Zali *et al*. (2011) studied 17 chickpea genotypes to determine the association between genetic parameters and traits in chickpea genotypes. Heritability values were greater for days to maturity (98.43 *per cent*), days to 50 *per cent* flowering (98.19 *per cent*), plant height (58.87 *per cent*), number of secondary branches (45.8 *per cent*), number of primary branches (42.03 *per cent*) and number of seeds plant$^{-1}$ (35.42 *per cent*), indicating that these traits are controlled mainly by additive genes.

Qurban Ali *et al.* (2012) studied eighty chickpea genotypes and were evaluated for genetic variability for morpho-physiological and quality traits in chickpea. The results showed that highest values of heritability and genetic advance were found for 100- seed weight, proteins, chlorophyll contents, pods plant$^{-1}$, leaf area and grain yield.

Kumar Abhishek *et al*. (2012) conducted an experiment to estimate the genetic variability in early segregating population in chickpea. High genotypic and phenotypic coefficient of variation was observed for 100 seed weight followed by seed yield plant$^{-1}$ and plant height. Hundred seed weight followed by harvest index, number of pods plant$^{-1}$ and seed yield plant$^{-1}$ exhibited high estimates of heritability as well as genetic advance.

Anita Babbar *et al*. (2012) evaluated forty four promising lines of chickpea. The maximum genotypic coefficient of variation was noticed for damaged pod percentage, total number of seeds plant$^{-1}$ and total number of pods plant$^{-1}$. Days to 50 *per cent* flowering, days to maturity, plant height, 100 seed weight and seed yield plant$^{-1}$ showing high heritability coupled with medium genetic advance as percentage of mean, whereas, number of seeds plant$^{-1}$ and number of pods plant$^{-1}$ showed medium heritability and high genetic advance as percentage of mean.

Jadhav *et al*. (2012) revealed that days to maturity exhibited highest range of variability followed by number of seeds plant$^{-1}$, number of pods plant$^{-1}$, days to 50 *per cent* flowering, harvest index, seed yield plant$^{-1}$, 100 seed weight, plant height and number of secondary branches plant$^{-1}$. Similar values for genotypic coefficient of variation and phenotypic coefficient of variation were recorded for 100 seed weight, harvest index, seed yield plant$^{-1}$, number of seeds plant$^{-1}$, number of pods plant$^{-1}$, days to maturity, days to 50 *per cent* flowering indicating that these characters are least affected by environment. High heritability with high genetic advance was observed for seed yield plant$^{-1}$, secondary branches plant$^{-1}$, 100 seed weight and number of seeds per plant due to additive gene effect.

Kanouni *et al*. (2012) revealed that the seed yield ranged from 266 kg/ha (FLIP06-58C) to 1020 kg/ha (FLIP 06-60C). The phenotypic coefficient of variation was higher than the genotypic coefficient of variation indicating the environmental influence for all the traits.

The phenotypic coefficient of variation was highest for drought tolerance score (44.54 *per cent*), followed by plant vigor (32.24 *per cent*), seed yield plant$^{-1}$ (28.47 *per cent*) and pods plant$^{-1}$ (27.59 *per cent*). Similarly, the genotypic coefficient of variation was highest for drought tolerance (39.27 *per cent*), followed by plant vigor, seed yield and pods plant$^{-1}$. Heritability for days to maturity, days to flowering and drought tolerance was greater than the heritability of the other traits.

Uday Chand Jha *et al*. (2012) studied thirty chickpea genotypes for seed yield and its components for asessing genetic variability. Analysis of variance for seed yield and its component showed significant differences among the genotypes for all the nine traits and reported highly significant and positive genotypic association were found between primary branches plant$^{-1}$ and number of pods plant$^{-1}$, plant height and days to maturity, days to maturity and number of pods plant$^{-1}$, number of seeds pod$^{-1}$ and days to 50 *per cent* flowering, days to maturity and seed yield plant$^{-1}$ and similarly 100 seed weight and seed yield plant$^{-1}$ were found.

Neelu Kumari *et al*. (2013) assessed genetic variability among 32 advanced breeding lines. Highest genotypic coefficient of variance was found in seed yield plant$^{-1}$. Heritability in broad sense ranged from 55 *per cent* for total yield (t/ha) followed by 53 *per cent* for days to 50 *per cent* flowering, High expected genetic advance coupled with high heritability estimate was obtained for plant height, number of secondary branches plant$^{-1}$ , number of pods plant$^{-1}$, and seed yield plant$^{-1}$.

Parashi and Lad (2013) determined genetic variability, genetic advance, and heritability in chickpea. They revealed that the characters seed yield plant$^{-1}$ exhibit highest range of variability followed by days to maturity, number of pods plant$^{-1}$.

Anjani Kumar Singh *et al*. (2014) Studied twenty nine genotypes of chickpea indicated that both liner and non-liner components were responsible for the expression of traits. However, the liner component was found larger in magnitude than the non-liner component, suggesting that variation in the performance of different cultivars could be predicted. High phenotypic and genotypic coefficient of variation coupled with high heritability and genetic advance as *per cent* of mean were also reported for seed yield plant$^{-1}$, number seeds pod$^{-1}$ and number of pods plant$^{-1}$ indicating predominance of additive gene effects in controlling these characters.

Aher *et al*. (2014) studied 38 different genotypes of chickpea and revealed presence of sufficient variability with high heritability for most of the yield components.

Ovais Hamid Peerzada *et al*. (2014) studied thirty six genotypes of chickpea. High genotypic (31.68) and phenotypic (31.82) co-efficient of variance were recorded for number of pods plant$^{-1}$. High heritability (99.8) coupled with high genetic advance (52.19) were recorded for seed yield plant$^{-1}$ and number of pods plant$^{-1}$. Hence, these characters indicate the presence of a considerable proportion of total variability due to genetic causes and may serve as effective selection parameter during breeding program for crop improvement.

Rajkumar Kuldeep *et al*. (2014) determined the genetic variability for seed yield and its component characters in 100 advanced breeding lines of chickpea. The high genotypic coefficient of variation and phenotypic coefficient of variation were observed for seed yield plant$^{-1}$, 100- seed weight, harvest index, number of effective pods plant$^{-1}$, total number of pods plant$^{-1}$ and number of secondary branches. High heritability with high genetic advance as percentage of mean was noted for seed yield plant$^{-1}$, followed by 100 seed weight, harvest index, number of effective pods per plant and total number of pods plant$^{-1}$ indicated that selection may be effective for these characters.

Sachin Parhe *et al*. (2014) conducted an experiment with fifty one genotypes of chickpea. Seed yield plant$^{-1}$ had maximum phenotypic and genotypic coefficient of variation, followed by 100 seed weight. High magnitude of heritability (broad sense) was recorded for 100 seed weight. High heritability coupled with high genetic advance was observed for number of pod plant$^{-1}$, 100 seed weight, days to 50 *per cent* flowering and Plant height suggested that, the role of additive gene effect and possibilities of achieving high genetic advance through selection.

Sharanappa *et al*. (2014) studied on thirty chickpea genotypes. High genotypic coefficient of variation was observed for internode distance followed by seed yield plant$^{-1}$ and harvest index. The traits plant height, angle between primary branches and ground, angle between primary branches and secondary branches, number of pods plant$^{-1}$, biological yield plant$^{-1}$ and harvest index exhibited high heritability coupled with high expected genetic advance indicating the scope for improvement and genetic gain through the selection for these traits.

Kamla Desai *et al*. (2015) evaluated 48 diverse chickpea genotypes .The highest genotypic coefficient of variation was observed for 100-seed weight followed by methionine content, number of pods plant$^{-1}$, seed yield plant$^{-1}$ and number of seeds pod$^{-1}$. High heritability coupled with high genetic advance was observed for methionine content, 100 seed weight, pods plant$^{-1}$ and days to flowering indicating the predominance of additive gene action.

Kunj Chandra *et al*. (2015) conducted an experiment consisting of seven mutagenic populations of chickpea .The results on heritability and genetic advance indicated that the isolation of mutants from $M_4$ population with high number of secondary branches plant$^{-1}$, high number of pods plant$^{-1}$, high 100 seed weight, high harvest index and high seed yield plant$^{-1}$ is possible in advanced generations.

### 2.3 CORRELATION AND PATH ANALYSIS

The idea of correlation was presented by Galton (1889) and later elaborated by Fisher (1918) and Wright (1921). Correlation co-efficients measures the mutual relationship between various plant characters. Based on the association among yield components one can formulate the effective selection procedure for yield improvement. The techniques of path co-efficient analysis was originally developed by Wright (1921) but the technique was first used for plant selection by Dewey and Lu (1959).

Singh *et al.* (1990) studied correlation and path coefficient analysis, showed that biological yield and harvest index were the major direct contributors to seed yield. The 100 seed weight, plant height, days to flowering and maturity and protein content contributed to seed yield mainly through indirect effect via biological yield and harvest index.

Path analysis is standardized partial regression co-efficient into measures of direct and indirect effects of a set of independent variables on the dependent variables. In this regard, Mustafa Guler *et al.* (2001) found positive and significant relationships between the number of seeds and the number of pod plant$^{-1}$, between the number of seeds plant$^{-1}$ and the number of pods plant$^{-1}$, negative and significant relationships were determined between the number of seeds plant$^{-1}$ and 100 seed weight.

Muhammad Arshad *et al.* (2004) studied correlation and path coefficients for yield and its components in 24 advanced lines of chickpea. Grain yield had positive and significant correlation with plant height, number of pods plant$^{-1}$, 100 seed weight and biological yield. High direct effects were contributed by biological yield and harvest index although the later had negative association with grain yield. Biological yield and harvest index should be given more consideration while deciding about selection criteria of genotypes for rainfed conditions**.**

Jeena *et al.* (2005) concluded that seed yield was significantly and positively correlated with plant height, length of pod bearing branch, secondary branches plant$^{-1}$, number of pods plant$^{-1}$, 100-seed weight, Biological yield plant$^{-1}$ and harvest index.

Meena *et al.* (2006) studied correlation and revealed higher estimates of genotypic correlation coefficient than the corresponding phenotypic component. The seed yield showed significant positive correlations with 100 seed weight, number of pods plant$^{-1}$. biological yield, plant height at both genotypic and phenotypic levels. Significant negative correlation of seed yield was observed with days to maturity at both genotypic and phenotypic levels.

Derya Ozveren Yucel *et al.* (2006) conducted an experiment on correlations between yield and yield components in 15 kabuli chickpea genotypes. Positive and significant ($P < 0.05$) relationships were determined between seed yield plant$^{-1}$ and plant height, first pod height, secondary branch, total pod, and number of pods and number of seeds plant$^{-1}$. The path coefficient analysis based on seed yield plant$^{-1}$ as a dependent variable, revealed that all of the other traits except days to flowering, first pod height, and total pod number, exhibited high positive direct effects. Number of seeds and full pods showed the highest direct influence with 47.49 *per cent* and 44.73 *per cent*, respectively.

Kanaka Durga *et al.* (2007) reported that plant height and pods plant$^{-1}$ were significantly and positively correlated with seed yield. Hence, more emphasis should be given to these characters for effective selection.

Abbas Biabani *et al*. (2010) studied the relationships between grain yield and the other characteristics with two cultivars of chickpea and revealed that seed yield had highly positive correlation with filled pod plant$^{-1}$.

Ozveren Yucel *et al*. (2010) evaluated 22 genotypes of chickpea. The path co-efficients analysis based on seed yield as a dependent variable, revealed that harvest index had the greatest direct effect on seed yield with the ratio of 56.04 *per cent*. Both correlation and path analyses indicated that harvest index was the major direct contributor to seed yield. They suggested that selection for high seed yield should be based on selecting high harvest index plants in chickpea.

Lal Hussain Akhtar *et al*. (2011) revealed interrelationships for seed yield and its components in 20 advance genotypes of chickpea. Significant and positive correlations were found between yield and 100-seed weight, number of pods plant$^{-1}$ and plant height.

Qurban Ali *et al*. (2012) studied eighty chickpea genotypes and were evaluated for correlation analysis in morpho-physiological and quality traits in chickpea. Results revealed that the correlation for leaflets per leaf, chlorophyll contents, 100-seed weight and leaf area with pods plant$^{-1}$, proteins with 100-seed weight, proteins and biomass plant$^{-1}$ with grains plant$^{-1}$ were positive and significant at both genotypic and phenotypic levels.

Zali *et al*. (2011) evaluated 17 chickpea genotypes to determine the association between genetic parameters and traits in chickpea. Number of seeds plant$^{-1}$ and 100-seed weight had a positive direct effect on seed yield. Number of seeds plant$^{-1}$, number of secondary branches, 100-seed weight, number of pods plant$^{-1}$, number of primary branches and plant height also had positive and highly significant phenotypic correlations with seed yield.

Anita Babbar *et al*. (2012) reported that seed yield plant$^{-1}$ showed high significant positive correlation with total number of seeds plant$^{-1}$, total number of pods per plant, biological yield, plant height and 100 seed weight, whereas significant negative correlation with days to 50 *per cent* flowering and damaged pod percentage.

Kumar Abhishek *et al*. (2012) studied character association and path analysis in early segregating population in chickpea. They revealed that seed yield plant$^{-1}$ exhibited significant and positive correlation with harvest index, 100 seed weight and number of pods plant$^{-1}$ at both phenotypic and genotypic level. Path analysis indicated that plant height, days to 50 *per cent* flowering and number of pods plant$^{-1}$ had high direct effect on seed yield at both phenotypic and genotypic levels.

Dar *et al*. (2012) studied correlation and path analysis and indicated that number of pods plant$^{-1}$, number of branches plant$^{-1}$, plant height and 100 seed weight could be useful as selection indices for development of high yielding genotypes of chickpea.

Kanouni *et al*. (2012) evaluated sixty genotypes of chickpea and they revealed positive significant ($P < 0.05$) relationships were found between seed yield plant$^{-1}$ and traits pods plant$^{-1}$, 100 seed weight and plant height. The genotypic path coefficient analysis based on seed yield plant$^{-1}$ as a dependent variable revealed that drought tolerance score, 100 seed weight, plant height and number of pods plant$^{-1}$ exhibited high positive direct effects. Days to maturity, vigour and 100 seed weight showed the highest direct influence. They suggested that drought tolerance score and number of pods plant$^{-1}$ can be used as selection criteria for improving seed yield for drought stress environments

Nihal Kayan and Sait Adak (2012) revealed the relationship between yield and yield components and noted that plant height, biological yield plant$^{-1}$ and number of pods plant$^{-1}$ can be considered as the most important yield variables in chickpea. High yield of chickpea plants can possibly be obtained by selecting breeding materials with high plant height, biological yield plant$^{-1}$ and number of pods plant$^{-1}$.

Uday Chand Jha *et al.* (2012) studied thirty chickpea genotypes for seed yield and its components for estimating correlation co-efficient. Highly significant and negative genotypic correlation between primary branches plant$^{-1}$ and plant height, primary branches plant$^{-1}$ and plant width, primary branches per plant and days to 50 *per cent* flowering, primary branches plant$^{-1}$ and days to maturity, plant height and plant width, plant height and number of pods plant$^{-1}$ were observed. The correlation between 100 seed weight and seed yield showed highest correlation coefficient.

Neelu Kumari *et al.* (2013) assessed genetic variability among 32 advanced breeding lines and found that grain yield plant$^{-1}$ had positive and significant association with biological yield, harvest index, test weight.

Samad (2014) studied Correlation, path coefficients in eight irradiated chickpea lines for eleven quantitative characters to design the selection strategy towards higher yield. Genotypic correlation coefficients were higher than the phenotypic correlation coefficients. Seed weight plant$^{-1}$ was positively correlated with days to maximum flower, number of primary branches at maximum flower, number of secondary branches at maximum flower, plant weight after fully dry, pod weight plant$^{-1}$ and number of seeds plant$^{-1}$ both at phenotypic and genotypic levels. Pod weigh plant$^{-1}$ and number of seeds per plant exhibited high significant positive correlation on seed weight plant$^{-1}$. Number of seeds plant$^{-1}$ had the highest positive direct effect of 1.077 *per cent* and 1.334 *per cent* on seed weight plant$^{-1}$ at both levels, respectively whereas pod weight plant$^{-1}$ showed positive direct effect of 0.346 *per cent* at genotypic levels.

Rajkumar Kuldeep *et al.* (2014) worked on the correlation and path analysis for seed yield and its component characters in 100 advanced breeding lines of chickpea. Analysis of correlation revealed that seed yield per plant was positively and significantly correlated with plant height, number of primary branches, number of secondary branches, number of pods plant$^{-1}$, number of effective pods plant$^{-1}$ and 100 seed weight indicating that these three traits were main yield attributing traits. The Path analysis indicated that number of effective pods plant$^{-1}$ and 100 seed weight had maximum direct effect on seed yield.

Sharanappa *et al*. (2014) conducted an experiment on thirty chickpea genotypes. High significant positive genotypic correlation was observed for plant height, number of total branches, number of pods plant$^{-1}$, 100 seed weight, biological yield, harvest index with seed yield plant$^{-1}$.

Sachin Parhe *et al*. (2014) studied correlation among yield components and their direct and indirect influences on grain yield they observed significant correlation of seed yield with traits, number of primary branches plant$^{-1}$, number of secondary branches plant$^{-1}$, plant height, 100 seed weight and number of pods plant$^{-1}$. Path coefficient analysis revealed that 100 seed weight, number of pods plant$^{-1}$ and number of secondary branches plant$^{-1}$ had the highest positive direct effects on grain yield. Improvement of the grain yield can be immensely efficient via 100 seed weight, number of pods plant$^{-1}$, number of primary branches plant$^{-1}$ and number of secondary branches plant$^{-1}$.

Kunj Chandra *et al*. (2015) conducted an experiment on mutagenic populations of chickpea. All the yield component traits exhibited positive and significant association with seed yield plant$^{-1}$ at phenotypic level except plant height and number of primary branches plant$^{-1}$ in both $M_3$ and $M_4$ generations.

# III MATERIAL AND METHODS

The present investigation was carried out during Rabi-Summer 2014-15 at the experimental plots of Zonal Agricultural Research Station (ZARS), In rabi-2015 crop was sown in Main Agricultural Research Station (MARS), Hebbal, Bengaluru. The experimental site located at an altitude of 930 m above mean sea level 12º 58' North latitude and 77º 35' East longitude. The material used and methodology adopted for collection, analysis and interpretation of data are presented in this chapter.

## 3.1 EXPERIMENTAL MATERIAL

The material for the present study consists of three genotypes, A-1, JG 11, and JAKI 9218 designated as females and three genotypes, JG 315, HC 5, JG 24, designated as males. The genotypes were procured from AICRP on Chickpea, GKVK, Bengaluru. Salient features of the lines and testers were given in Table 1a and Table 1b. These lines and testers were crossed in a line × tester mating design to synthesize nine crosses.

## 3.2 EXPERIMENTAL DESIGN AND LAYOUT

During Rabi-Summer 2014-15 crosses were effected in Line X Tester mating design. During early kharif 2015 Syntesized $F_1$`s (9 hybrids) along with their 6 parents (three lines and three testers) and a standard check (JG 11) were evaluated for quantitative traits in RCBD design with two replications. Each genotype (Parents, Hybrids and a Check) was grown in two rows of 3 m length consisting of 30 plants per row with a spacing of 10 cm between plants within a row and 30 cm between rows at experimental plots of Zonal Agricultural Research Station (ZARS), University of Agricultural Sciences, Gandhi Krishi Vignana Kendra (GKVK), Bengaluru.

During Rabi 2015, based on heterosis**,** nine $F_1$ crosses were forwarded to $F_2$ generation and individual plant observations were recorded in four crosses viz., A-1 × JG 315, A-1 × HC 5, JG 11 × JG 24, JAKI 9218 × HC 5. These crosses were selected based on the population size in the field at Main Agricultural Research Station (MARS), Hebbal, Bengaluru. Variability for grain yield and its component traits were assessed and interrelationship among quantitative traits was explored. All the recommended package of practices was followed to raise a healthy crop.

## 3.3 RECORDING OF OBSERVATIONS

During early *kharif* 2015, five representative plants in each genotype (hybrids, parents and checks) were tagged at random from each replication. During Rabi 2015, In $F_2$ population, individual plant observation were recorded in four crosses *viz.*, A-1 × JG 315, A-1 × HC 5, JG 11 × JG 24, JAKI 9218 × HC 5. Crosses were selected based on the population size in the field and observation was recorded in randomly selected plants for the following traits.

1. Days to 50 *per cent* flowering
2. Plant height
3. Number of primary branches
4. Number of pods plant$^{-1}$
5. Seed yield plant$^{-1}$
6. 100 - seed weight
7. Days to maturity

**3.3.1: Days to 50 *per cent* flowering**

Number of days taken from the day of sowing to the day on which 50 *per cent* of plants flowered were recorded and expressed in days.

**3.3.2: Plant height**

The plant height was recorded in centimeter (cm) from ground level to the growing tip at the time of maturity.

**3.3.3: Number of primary branches plant$^{-1}$**

Number of primary branches were counted in all the five labeled plants in $F_1$ and individual plants in $F_2$ and average value gives the number of primary branches plant$^{-1}$.

**3.3.4: Number of pods plant$^{-1}$**

Number of pods per plant were counted in each of the five selected plants in $F_1$ and 250-300 individual plants from each cross in $F_2$ and the mean was calculated.

**3.3.5: Seed yield plant$^{-1}$**

Total seeds obtained from five randomly selected plants in $F_1$ and 250-300 individual plants from each cross in $F_2$ were weighed in grams and the mean was calculated.

**3.3.6: Hundred seed weight**

Weight of 100 randomly selected seeds from each labelled plants was averaged as test weight for each of the randomly selected plants and expressed as mean of treatment in grams.

**Plate 1: Evaluation of $F_1$'s along with parents**

### 3.3.7: Days to maturity

Number of days taken from sowing to physiological maturity was recorded in $F_1$ and $F_2$ generations.

**Table 1a. Details of the lines used and their sources and salient features**

| **Parents** | **Source** | **Salient Features** |
|---|---|---|
| A-1 | AICRP on Chickpea, GKVK, Bengaluru | Highly adopted local variety |
| JAKI-9218 | AICRP on Chickpea, GKVK, Bengaluru | Resistance to wilt, root rot, collar rot |
| JG-11 | AICRP on Chickpea, GKVK, Bengaluru | Early, bold seeded, resistant to wilt and highly adopted |

**Table 1b. The details of the testers used and their sources and salient features**

| **Parents** | **Source** | **Characteristics** |
|---|---|---|
| JG-24 | AICRP on Chickpea, GKVK, Bengaluru | High yield and moderately resistance to wilt |
| JG – 315 | AICRP on Chickpea, GKVK, Bengaluru | Tall and erect type, wilt resistant |
| HC-5 | AICRP on Chickpea, GKVK, Bengaluru | Tall and erect type. |

### 3.4: Statistical Analysis

Replication-wise mean values of five randomly selected plants in each entry were computed for each of the characters and were used for statistical analysis.

### 3.4.1 General ANOVA for parents and hybrids

Mean values computed on selected productivity traits in each of the nine genotypes including three lines and three testers, nine hybrids and one check were subjected to analysis of variance (Panse and Sukhatme, 1967).

The model of ANOVA (parents and hybrids) is given below.

**ANOVA for combing ability**

| Source of variation | Df | MSS | |
|---|---|---|---|
| Replications | (r – 1) | $M_r$ | $M_r/M_e$ |
| Genotypes | (g – 1) | $M_g$ | $M_g/M_e$ |
| **Parents** | (p -1) | $M_p$ | $M_p/M_e$ |
| Lines | (l -1) | $M_l$ | |
| Testers | (t -1) | $M_t$ | |
| Lines x Testers | (l -1) (t-1) | $M_{lt}$ | |
| **Hybrids** | (lt -1) | $M_h$ | $M_h/M_e$ |
| **Parents Vs Hybrids** | 1 | $M_{ph}$ | $M_{ph}/M_e$ |
| Error | (g – 1) (r – 1) | $M_e$ | |
| Total | (ltr – 1) | | |

Where,

r =Number of replications

g=Number of genotypes

p=Number of parents (l+t)

t=Number of testers and

l=Number of lines

The significance of every entry was tested by comparing calculated ‘F’ value with table ‘F’ value at 1 *per cent* and 5 *per cent* probability levels.

### 3.4.2. Combining Ability Analysis

The mean values computed from the observations recorded for selected productivity traits in each genotype and replication on five randomly selected plants were subjected to line × tester analysis (Kempthrone, 1957), keeping in view the caution given by Arunachalam (1974). Statistical analysis of the data was carried out using statistical program WINDOWSTAT 8.0 for combining ability analysis. The structure of ANOVA for line × tester analysis is as follows:

**Structure of ANOVA for line × tester analysis**

| Source | Df | MSS | Components of expected MSS |
|---|---|---|---|
| Replication | (r – 1) | | |
| Crosses | (mf – 1) | | |
| Lines | (f – 1) | $M_1$ | $\sigma_e^2 + r\sigma^2_{sca} + r.m.\sigma^2_{gca}$ |
| Testers | (m – 1) | $M_2$ | $\sigma_e^2 + r\sigma^2_{sca} + r.f.\sigma^2_{gca}$ |
| Line × Tester | (f – 1 ) (m – 1) | $M_3$ | $\sigma_e^2 + r[\text{Cov.(F.S.)} - 2\,\text{Cov.(HS)}]$ |
| Error | (r – 1) (g – 1) | $M_4$ | $\sigma_e^2$ |
| Total | (gr – 1) | | |

Where,

g = (m + f + mf)

HS = Half sibs

FS = Full sibs

$\sigma^2_{gca}$ = Covariance HS

$\sigma^2_{sca}$ = [Covariance (FS) – 2 Cov (HS)]

From the mean sum of squares, covariance of full sibs and covariance of half sibs were estimated.

$$\text{Covariance of FS} = \frac{M_1 + M_2 + M_3 - 3M_4 + 6r.\text{Cov (HS)} - r\,(m+f)\,.\text{Cov (HS)}}{3r}$$

$$\text{Covariance of half sibs (average)} = \frac{M_1 + M_2 - 2M_3}{r\,(m+f)}$$

Variance due to gca effects ($\sigma^2 gca$) = ½ Cov (HS) (average)

Variance due to sca effects ($\sigma^2 sca$) = [Cov (FS) – 2 Cov. (HS)]

$\sigma^2_{gca}$ for females = $\dfrac{M_1 - M_3}{r.m.}$

$\Sigma^2_{gca}$ for males = $\dfrac{M_2 - M_3}{r.f.}$

$\sigma^2_{sca} = \dfrac{M_3 - M_4}{r}$

Where,

$M_1$ = Mean sum of squares due to females

$M_2$ = Mean sum of squares due to males

$M_3$ = Mean sum of squares due to female x males

$M_4$ = Mean sum of squares due to error.

**3.4.3: Estimation of general and specific combining ability effects:**

The following linear model was used to estimate general combining ability (gca) and specific combining ability (sca) effects.

$$\mathbf{X_{ij} = \mu + g_i + g_j + S_{ij} + e_{ijk}}$$

Where,

$\mu$ = population mean

$g_i$ = gca effect of $i^{th}$ female parent

$g_j$ = gca effect of $j^{th}$ male parent

$S_{ij}$ = sca effect of $ij^{th}$ combination

$e_{ijk}$ = Error associated with the observation $X_{ijk}$

i = Number of female parents

j = Number of male parents

k = Number of replications

The individual effects were estimated as follows:

**(i) General combining ability effects**

**a) Line :** $$\hat{g}_i = \frac{x_{i..}}{mr} - \frac{x...}{mfr}$$

Where,

$x_{i..}$ = Total of i^th^ female parent over all male parents and replications.

x.. = Total of all hybrids over female and male parents

$\hat{g}_i$ = General combining ability effects of $i^{th}$ line

**b) Tester:** $$\hat{g}_j = \frac{x_{.j.}}{fr} - \frac{x...}{mfr}$$

Where,

x... = Total of all hybrids over female and male parents

$x_{.j.}$ = Total of $j^{th}$ male parent over all the female parents and replications

$\hat{g}_j$ = General combining ability effects of $j^{th}$ tester

**(ii) Specific combining ability effects**

$$S_{ij} = \frac{x_{ij.}}{r} - \frac{x_{i..}}{mr} - \frac{x_{.j.}}{fr} + \frac{x...}{mfr}$$

Where,

$S_{ij}$ = Specific combining ability effect of $ij^{th}$ combination

$X_{ij}$ = Total of $ij^{th}$ combination over all the replications

The standard errors for testing the significance of gca and sca effects were estimated using the following formulae:

Standard error (SE) of $g_i$'s = $\sqrt{\frac{m_4}{mr}}$

Standard error (SE) of $g_j$'s = $\sqrt{\frac{m_4}{fr}}$

Standard error (SE) of $S_{ij}$'s = $\sqrt{\frac{m_4}{r}}$

The estimates of $g_i$'s and $S_{ij}$'s were tested for their statistical significance by means of 't' test.

$$t_{g_i} = \frac{g_i - 0}{SE(g_i)}; \quad tg_j = \frac{g_j - 0}{SE(g_j)}; \quad ts_{ij} = \frac{s_{ij} - 0}{SE(s_{ij})}$$

### 3.4.4: Standard errors for testing the significance of gca and sca effects

The standard errors for testing the significance of gca and sca effects were estimated using the following formulae.

Standard error (SE) for gca effects of lines = SE $g_i$ = $(Me/tr)^{½}$

Standard error (SE) for gca effects of testers = SE $g_j$ = $(Me/lr)^{½}$

Standard error (SE) for sca effects of hybrids = SE $s_{ij}$ = $(Me/r)^{½}$

The estimates of $g_i$ and $s_{ij}$ were tested for their statistical significance by 't' test. For testing the significance of difference between gca effects of two lines (or two testers) and sca effects of hybrids, the standard errors are computed as follows

Standard error of $(g_i – g_j)$ for lines = $(2M_e/ tr)^{½}$

Standard error of $(g_i – g_j)$ for testers = $(2M_e/ lr)^{½}$

Standard error of $(s_{ij} – s_{kl})$ for crosses = $(2M_e/ r)^{½}$

The corresponding critical difference (CD) values were computed by multiplying SE value with $(2)^{½}$ and table't' value at 5 *per cent* and 1 *per cent* respectively.

CD = $(2)^{½}$ (SE) (table't' value for error degrees of df) at 5 and 1 *per cent*, respectively)

### 3.4.5: Proportional contribution of lines, testers and their interactions to total variance

*Per cent* contribution of lines, testers and their interaction towards total variability in each character was estimated by following the method of Singh and Choudhary (1977) as given below.

i) Contribution of lines = $\frac{SS\ (lines)}{SS\ (Crosses)} \times 100$

ii) Contribution of testers = $\frac{SS\ (testers)}{SS\ (crosses)} \times 100$

iii) Contribution of (l × t) = $\frac{SS\ (l \times t)}{SS\ (crosses)} \times 100$

Where,

SS (lines) = Sum of squares of lines

SS (testers) = Sum of squares of testers

SS (l x t) = Sum of squares of l × t interaction

SS (crosses) = Sum of squares of crosses from the ANOVA table of l x t analysis.

**3.5 Estimation of Heterosis**

Mid parent heterosis was calculated as per the procedure suggested by Fonseca and Patterson (1968) and used to ascertain the overall heterotic status of crosses.

$$\text{Mid parent heterosis} = \frac{(\overline{F1} - \overline{MP})}{\overline{MP}} \times 100$$

$$MP = \frac{P_1+P_2}{2}$$

Where,

$\overline{F}_1$ = Mean of $F_1$ hybrid

$\overline{MP}$ = Mid parent value

Standard heterosis over standard check JG-11 was estimated as follows,

i) Standard parent heterosis = $\frac{(\overline{F_1} - \overline{SC})}{\overline{SC}} \times 100$

Where,

$\overline{F_1}$ = Mean of $F_1$ hybrid

$\overline{SC}$ = Mean value of standard checks (JG-11).

Standard error (SE) was used to test the significance of mid parent/standard heterosis using the formula

$$\text{SE (MP heterosis)} = \sqrt{\frac{3m_4}{2r}}$$

$$\text{SE (SP heterosis)} = \sqrt{\frac{2\,m_4}{r}}$$

Where,

$M_4$ = Error mean sum of squares in ANOVA table of L × T analysis

r = Number of replication

C D = S.E. × table't' value at error df. × $\sqrt{2}$

### 3.5.1: Overall gca status of parents, sca and heterotic status of crosses

Since yield is associated with several other characters, positively with some and negatively with others, it is necessary to know the overall status of the parents/hybrids considering gca effects / sca effects, respectively for all the characters simultaneously. Therefore, overall status of a parent or a cross with respect to gca or sca was determined as per the method of Arunachalam and Bandyopadhyay (1979) with slight modification as suggested by Mohan Rao (2001). The modified procedure is described as under.

The estimates of general combining ability effects of parents, sca effects and mid-parent heterosis of hybrids were ranked by giving the highest rank for the parent or the cross which manifested the highest gca / sca effects and mid-parent heterosis, respectively in desirable direction. The lowest rank was given for parent or the cross with the lowest gca/sca effects and standard heterosis for a character, respectively. This was repeated for each selected productivity traits. The ranks obtained by the parent /hybrid were summed up across all the characters to arrive at a total score for each of the parent / cross. Further, the mean of the total scores of all the genotypes (parents and hybrids) was computed which was used as the final norm to ascertain the status of a parent or a hybrid for their gca / sca effects and mid-parent heterosis. The parent / hybrid whose total rank exceeded the final norm were given high (H) overall gca / sca / heterotic status, respectively. On the other hand, the parent or the cross, whose total rank was less than the final norm were given low (L) overall gca / sca / heterosis status, respectively.

Based on the overall parental gca status, the crosses were grouped into different categories *viz.*, High × High, High × Low, Low × High and Low × Low. The overall sca status of crosses *viz.*, High or Low was also mentioned under each category to draw inference.

### 3.6 Coefficient of variation

The components *viz.*, phenotypic, genotypic and environmental variances were utilized for estimation of coefficient of variation at both phenotypic and genotypic levels for all the characters were computed as suggested by Burton and Devane (1953).

#### 3.6.1: Phenotypic and genotypic variance

Phenotypic and genotypic components of variance in $F_2$ population for all the characters were computed using the formulae mentioned below.

i. Phenotypic variance = Total observed variance

ii. Genotypic variance = $\sigma^2_p$-$\sigma^2_e$

Where,

Environmental variance = $\sigma^2_{p1}+\sigma^2_{p2}+2\sigma^2_{F1}/4$

Where,

$\sigma^2_{p1}$= Phenotypic variance of parent 1 in a particular cross.

$\sigma^2_{p2}$= Phenotypic variance of parent 2 in a particular cross.

$\sigma^2_{F1}$= Phenotypic variance of $F_1$ of a particular cross

#### 3.6.2: Co- efficient of variability

Both genotypic and phenotypic co-efficient of variability for all the characters considered were computed by making use of the method suggested by Burton and Devane (1953).

i. Genotypic co-efficient of variability (GCV)

$$GCV = \frac{\sqrt{\sigma^2 g} \times 100}{\bar{X}}$$

Where,

$\sigma^2 g$ = Genotypic variance

$\overline{X}$ = General Mean

i. Phenotypic co-efficient of variability (PCV)

$$PCV = \frac{\sqrt{\sigma^2 \rho} \times 100}{\overline{X}}$$

Where,

$\sigma^2 \rho$ = Phenotypic variance

$\overline{X}$ = General Mean

PCV and GCV were classified as suggested by Robinson *et al*. (1954) and are given below.

| | |
|---|---|
| 0-10% | : Low |
| 10-20% | : Moderate |
| 20% and above | : High |

**3.6.3: Heritability ( $h^2$ )**

Heritability in broad sense for all the characters were composed as the ratio of genetic variance to the phenotypic variance as suggested by Johnson *et al*. (1955).

$h^2 = \sigma^2 g / \sigma^2 \rho \times 100$

Where,

$\sigma^2 g$ and $\sigma^2 \rho$ are the genotypic and phenotypic variance.

The heritability percentage was categorized as suggested by Robinson *et al*. (1954) as mentioned below.

| | |
|---|---|
| 0-30% | : Low |
| 30-60% | : Moderate |
| 60% and above | : High |

### 3.6.4: Genetic advance (GA)

Genetic advance for each character was worked out by adopting the formula given by Johnson *et al* (1955).

$$GA = h^2 \times k \times \sigma p$$

Where,

$h^2$ = heritability estimated

k = Selection differential which is equal to 2.06 at 5% intensity of selection

$\sigma$ p = phenotypic standard deviation

The genetic advance as parent mean was categorized as suggested by Johnson *et al*. (1955) and the same is given by

| | | |
|---|---|---|
| 0-10% | : | Low |
| 10-20% | : | Moderate |
| 20% and above | : | High |

### 3.7: Association analysis

### 3.7.1: Simple correlation:

The correlation co-efficients were calculated to determine the degree of association of character with yield and also among the yield components.

Phenotypic and genotypic correlation co-efficients were compared against 'r' values given in Fisher and Yates at n-2 degree of freedom at the probability levels of 0.05 amd 0.01 to test their significance.

Phenotypic and genotypic correlation were computed by using the formulae given by Sunder Raj *et al*. (1972).

$$rp = \frac{Cov.\ \rho\ (X, Y)}{\sqrt{\sigma^2 \rho_{x.}\ \sigma^2\ \rho_y}}$$

$$rg = \frac{Cov.\ g\ (X, Y)}{\sqrt{\sigma^2 g_{x.}\ \sigma^2 g_y}}$$

Where,

rg and rρ are genotypic and phenotypic correlations respectively.

Cov. g (X, Y) and Cov. ρ (X, Y) are genotypic and phenotypic covariance between the character X and Y.

$\sigma^2 g_x$ and $\sigma^2 g_y$ are genotypic variance of the characters X and Y

$\sigma^2 \rho_x$ and $\sigma^2 \rho_y$ are phenotypic variance of the characters X and Y.

**3.7.2: Path co-efficient analysis:**

Path co-efficient analysis was carried out using phenotypic correlation to know the direct and indirect effects of yield components on yield as suggested by Wright (1921) and illustrated by Dewey and Lu (1959).

Standard path co-efficients which are standard partial regression co-efficients were obtained by solving the following set of 'p' simultaneous equation through use of "Doolittle Technique".

$P_{01} + P_{02}\, r_{12} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ P_{0p}\, r_{1p} = r_{01}$

$P_{01}\, r_{21} + P_{02}\, r_{22} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ P_{0p}\, r_{2p} = r_{02}$

- 
- 
- 
- 

$P_{0p}\, r_{1p} + P_{0p}\, r_{2P} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ P_{0p} = r_{0p}$

Where,

$P_{01}$, $P_{02}$ ……………… $P_{0p}$ are the direct path co-efficients of variables 1, 2, …….P on the dependent variables 0.

$r_{12}$, $r_{13}$ …. $Pr_{1p}$……. r r(p-1) are the possible correlation coefficients between various independent variables and $r_{01}$, $r_{02}$ …. $r_{0p}$ are the correlations between dependent and independent variables.

The indirect effect of the $i^{th}$ variable *via* $j^{th}$ variable was obtained $P_{0j} \times r_{ij}$.

The contribution of the remaining unknown factors was measured as the residual factor and calculated as below:

$P^2_{0x} = 1 - (P^2_{01} + 2P_{01} P_{02} r_{12} + 2P_{02} P_{03} r_{13} + \ldots\ldots \ldots\ldots + P^2_{02} + 2P_{02} P_{03} r_{13} + \ldots\ldots \ldots\ldots + P^2_{0p})$

Residual factor x $= \sqrt{P^2_{0X}}$

# IV EXPERIMENTAL RESULTS

The results obtained from the present investigation on "Heterosis and $F_2$ genetic variability in selected crosses for quantitative traits in chickpea (*Cicer arietinum* (L.)" are presented under the following headings.

4.1 Mean performance of parental lines, testers and hybrids

4.1.1 Mean performance of lines and testers

4.1.2 Mean performance of crosses

4.2 Analysis of variance for parents and crosses

4.3 Analysis of variance for combining ability

4.4 Combining ability effects and gene action

4.4.1 General combining ability effects

4.4.2 Overall general combining ability status of parents

4.4.3 Specific combining ability effects

4.4.4 Proportional contribution of lines, testers and line × tester interaction

4.5 Variance due to general and specific combining ability

4.6 Heterosis

4.6.1 Standard Heterosis and Mid parent heterosis

4.6.2 Overall Specific combining ability and heterotic status of crosses

4.7 Genetic variability parameters

4.8 Correlation among different characters for yield and yield attributing traits

4.9 Path co-efficient for yield and yield attributing traits

## 4.1 Mean performance of parental lines, testers and hybrids

### 4.1.1 Mean performance of lines and testers

Mean performance of parents (lines and testers) is presented in Table-2, as described below:

**Table 2. Mean performance of parents in respect of seed yield and its attributing traits**

| Parents | Days to 50% flowering | Plant height (cm) | Number of primary branches | Number of pods plant$^{-1}$ | Seed yield plant$^{-1}$ (g) | 100 seed weight (g) | Days to maturity |
|---|---|---|---|---|---|---|---|
| **Lines** | | | | | | | |
| A-1 | 34.0 | 40.6 | 6.9 | 68.1 | 15.1 | 21.8 | 99.0 |
| JAKI 9248 | 44.0 | 51.3 | 5.3 | 44.8 | 9.8 | 17.9 | 102.0 |
| JG 11 | 34.0 | 44.9 | 4.6 | 40.0 | 11.3 | 26.4 | 92.0 |
| **Testers** | | | | | | | |
| HC -5 | 44.5 | 52.4 | 5.3 | 44.8 | 9.5 | 19.05 | 102.0 |
| JG 315 | 37.0 | 43.0 | 4.7 | 53.9 | 11.7 | 16.8 | 97.0 |
| JG 24 | 41.0 | 53.8 | 4.9 | 34.1 | 12.6 | 34.7 | 102.0 |
| S.Em.± | 0.6 | 2.1 | 1.3 | 10.9 | 2.3 | 0.9 | 2.0 |
| C.D @ P= 0.05 | 1.9 | 6.4 | 3.8 | 5.6 | 7.0 | 2.6 | 5.9 |
| C.V.% | 2.4 | 6.9 | 3.8 | 16.2 | 14.7 | 5.1 | 2.8 |

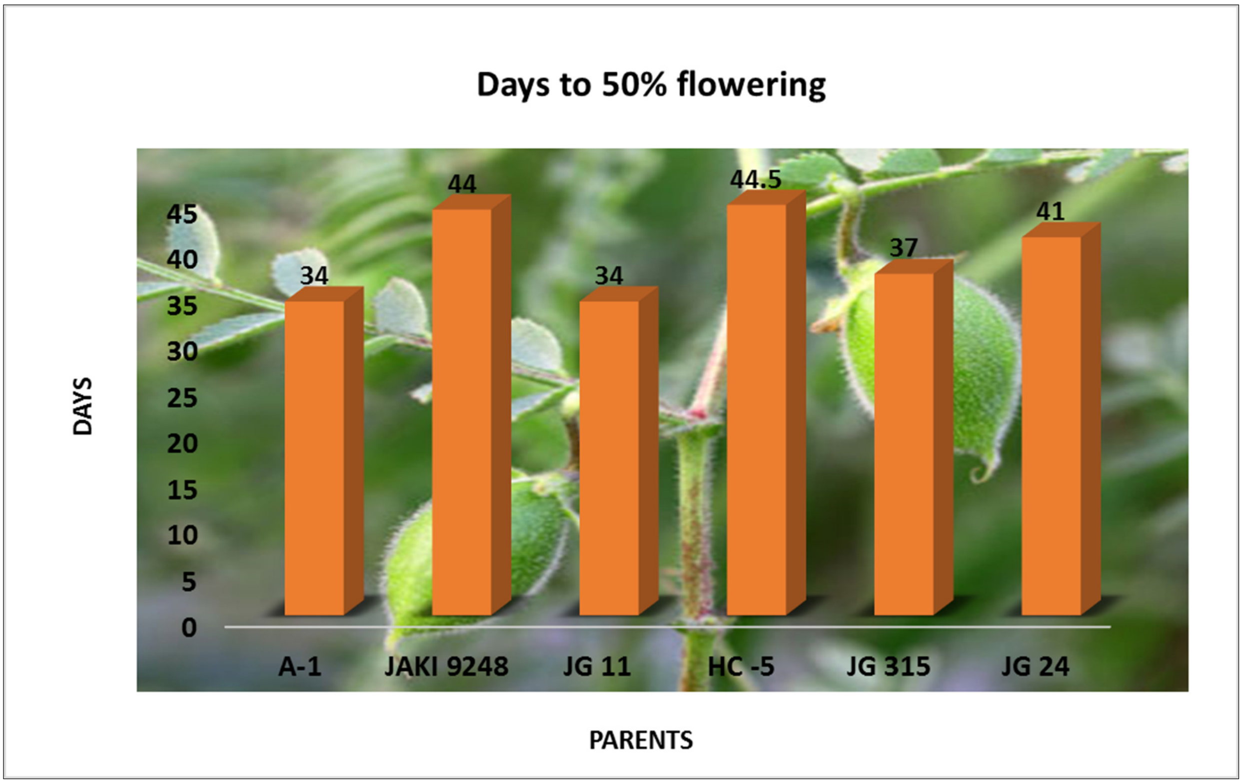


**Fig. 1: Mean performance of parents with respect to days to 50 *per cent* flowering**

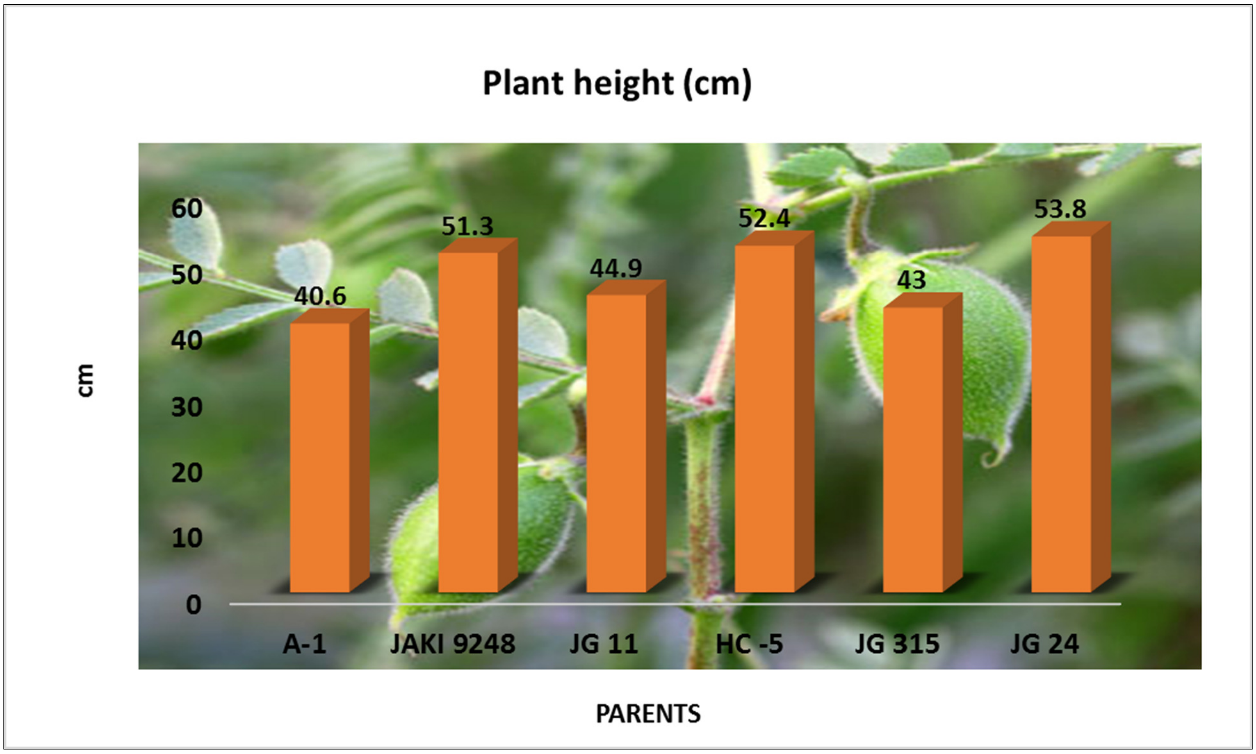


**Fig. 2: Mean performance of parents with respect to plant height (cm)**

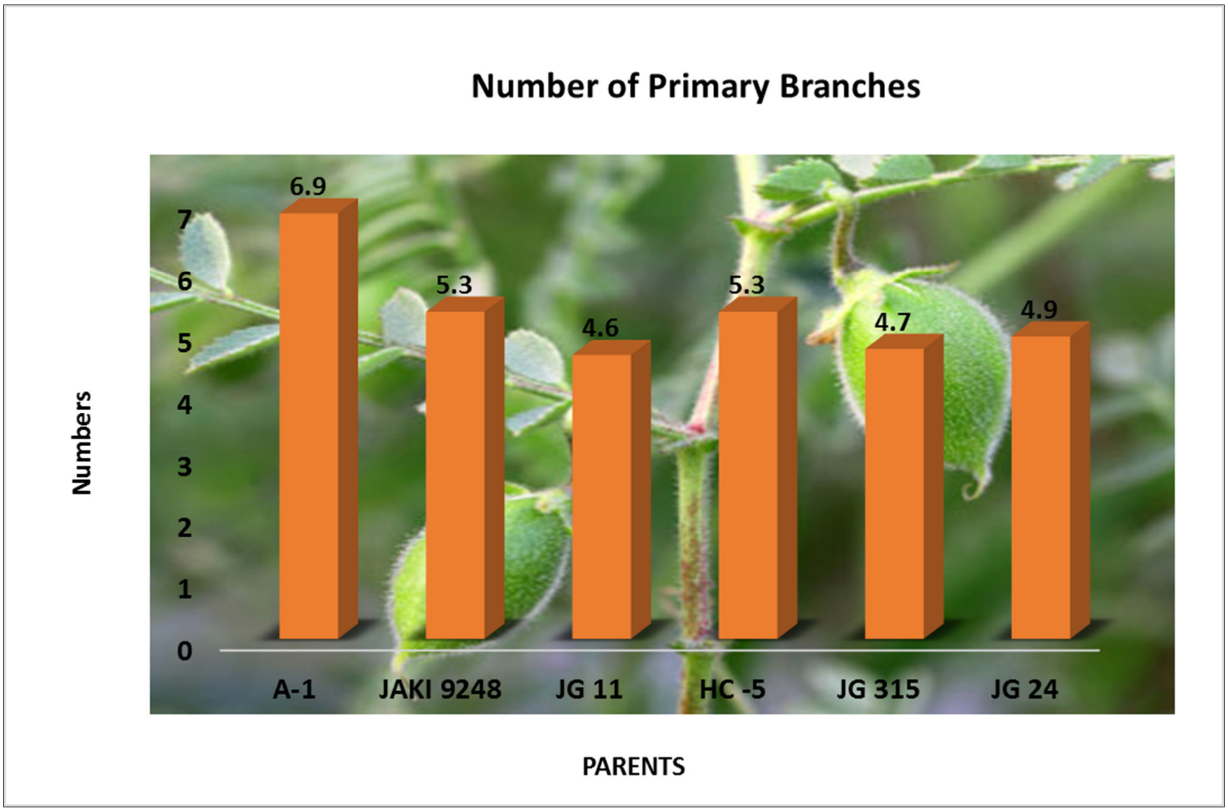


**Fig. 3: Mean performance of parents with respect to number of primary branches**

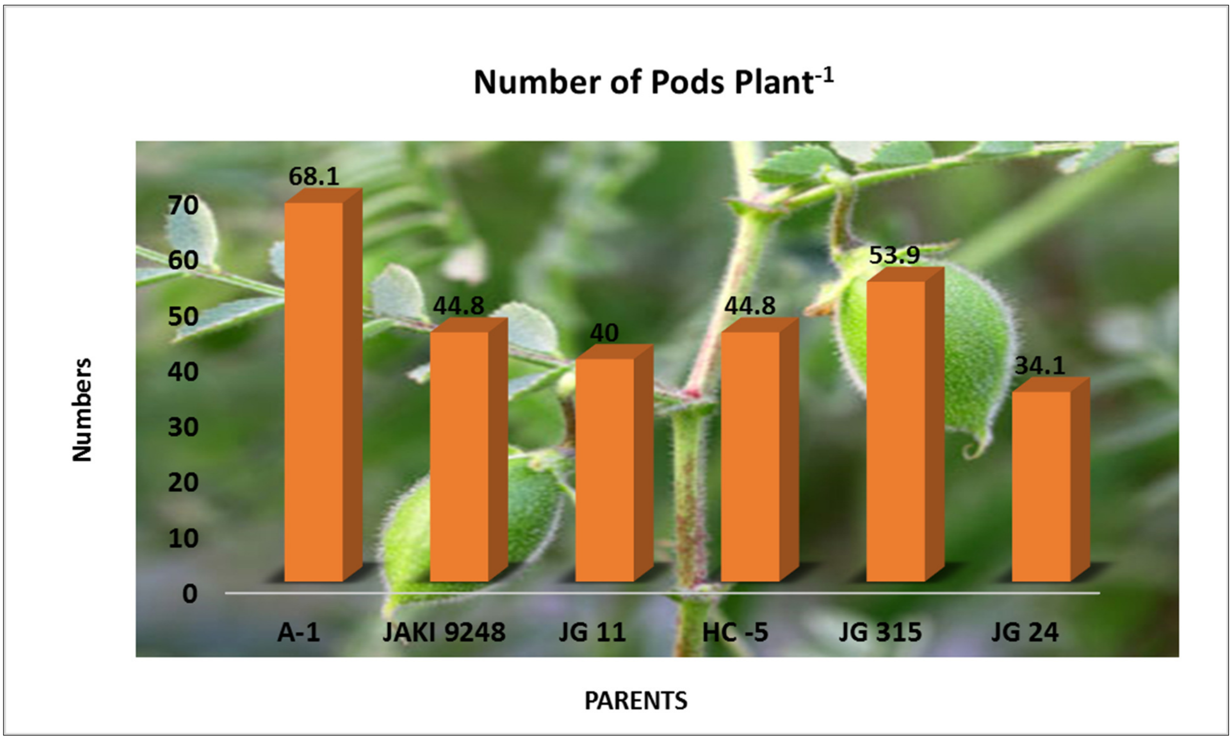


**Fig. 4: Mean performance of parents with respect to number of pods plant$^{-1}$**

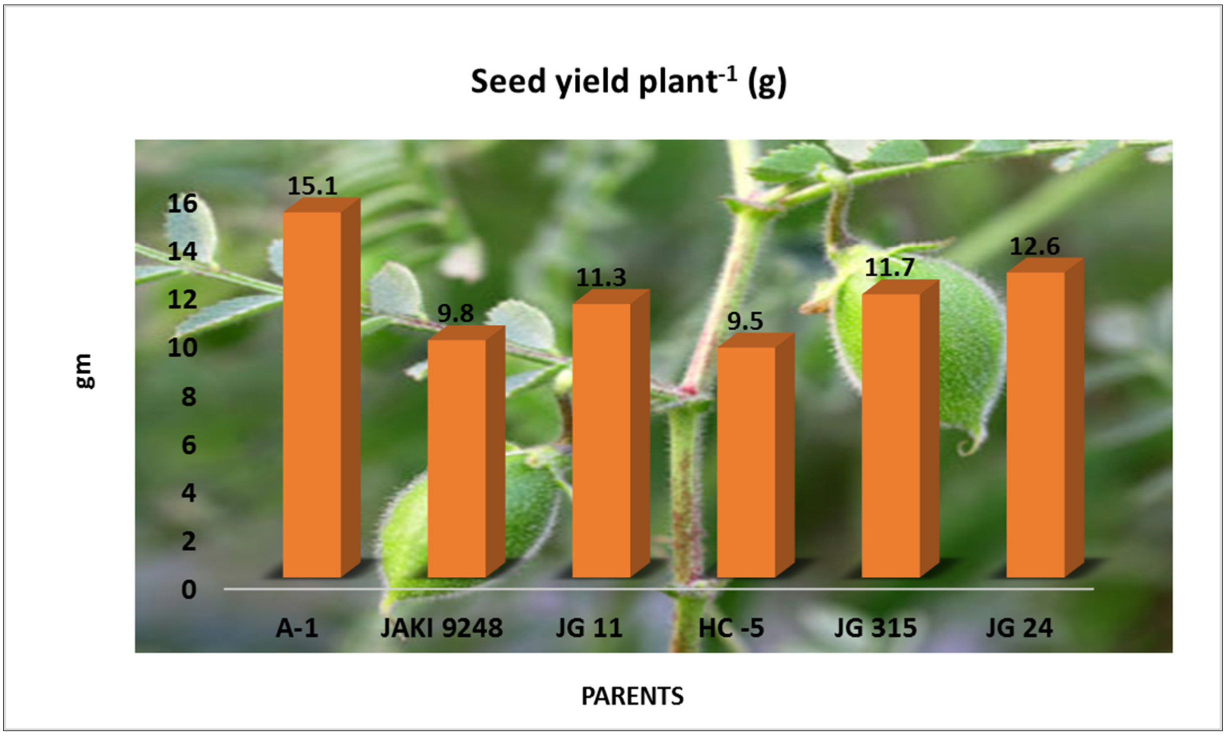


**Fig. 5: Mean performance of parents with respect to seed yield plant$^{-1}$**

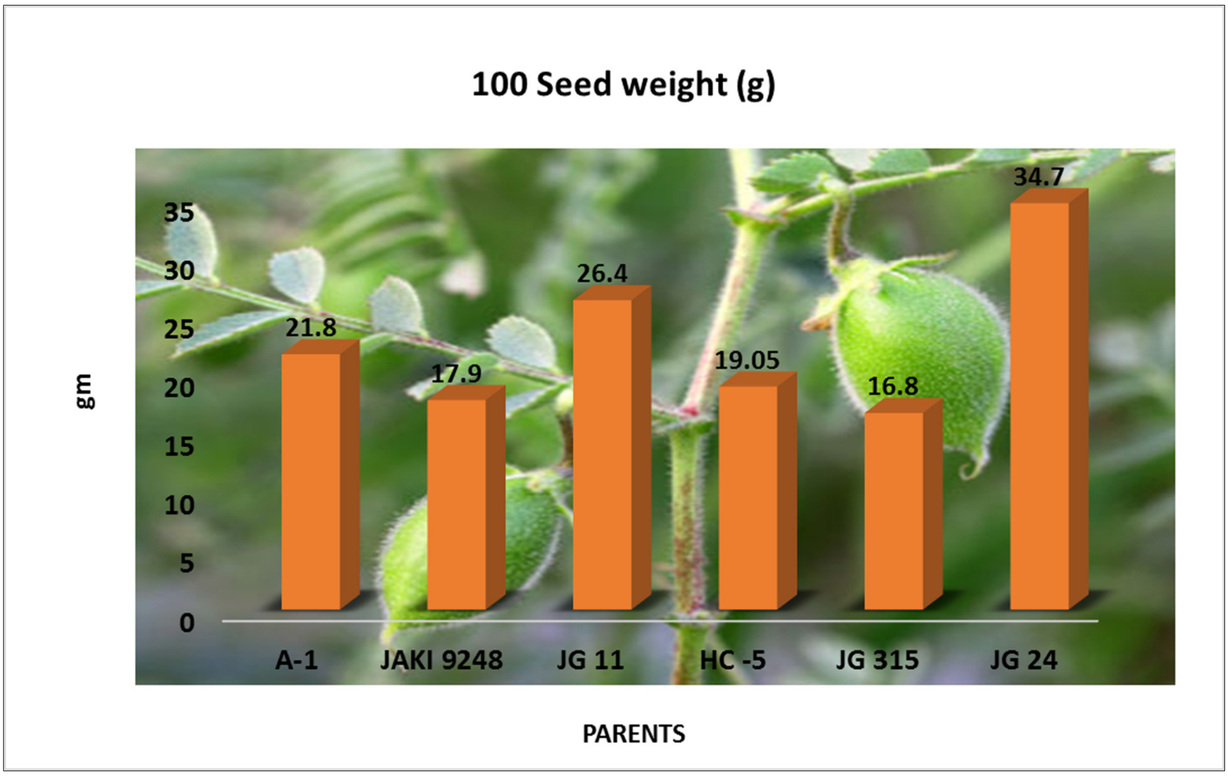


**Fig. 6: Mean performance of parents with respect to 100 seed weight (g)**

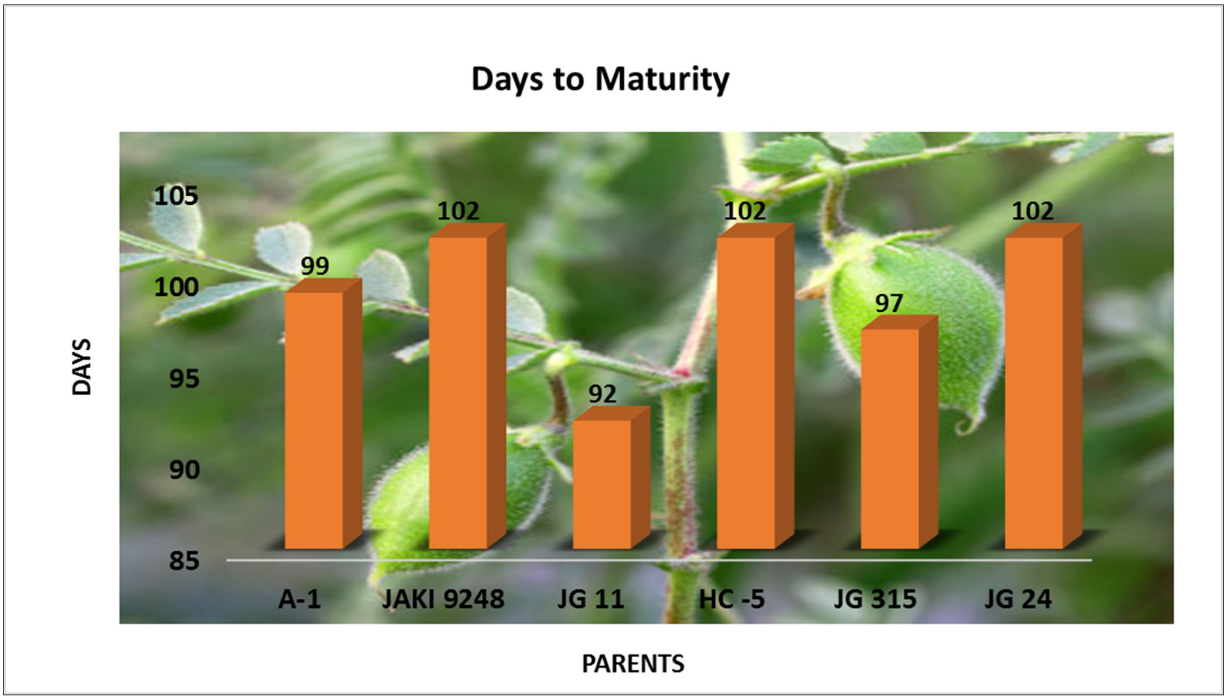


**Fig. 7: Mean performance of parents with respect to days to maturity**

#### 4.1.1.1 Days to 50 *per cent* flowering

Among 3 lines evaluated, A-1 and JG 11 was earliest to flower (34 days) while JAKI 9218 showed delayed flowering (44 days). Among the testers JG 315 was earliest to flower (37 days) followed by JG 24 (41 days) and HC 5 (44.5 days).

#### 4.1.1.2 Plant height (cm)

The line JAKI 9218 was tallest with a mean plant height of 51.3 cm followed by JG 11 (44.9 cm), while A-1 was shortest with a mean plant height of (40.6 cm). The tester JG 24 recorded-maximum plant height of 53.8 cm followed by HC 5 (52.4 cm), while JG 315 was shortest with a mean plant height of 43 cm.

#### 4.1.1.3 Number of primary branches

Among lines A-1 bears maximum number primary branches (6.9) followed by JAKI 9218 (5.3) while JG 11 have least number of primary branches (4.6). Among testers HC-5 was having maximum number primary branches (5.3) followed by JG 24 (4.9) while JG 315 was having least number of primary branches (4.7).

#### 4.1.1.4 Number of pods plant$^{-1}$

Among lines highest number of pods plant$^{-1}$ was observed in case of A-1 (68.1) followed by JAKI 9218 and the least number of pods plant$^{-1}$ was observed in JG 11 (40.0). Among testers, JG 315 recorded highest number of pods plant$^{-1}$ followed by HC 5 (44.8) and JG 24 (24.0) was having least number of pods plant$^{-1}$ (34.1).

#### 4.1.1.5 Seed yield plant$^{-1}$ (g)

Among lines the highest seed yield plant$^{-1}$ was noticed in case of A-1 (15.0 g) followed by JG 11 (11.28 g) and minimum in JAKI 9218 (9.7 g). The tester JG 24 exhibited highest seed yield plant$^{-1}$ (12.6 g) followed by JG 315 (11.6 g) and minimum in HC 5 (9.5 g).

#### 4.1.1.6 100 seed weight (g)

The maximum test weight was recorded by JG 11 (26.4 g) followed by A-1 (21.8 g) and minimum in JAKI 9218 (17.8 g). Among the tester JG 24 (34.6 g) was having maximum test weight followed by HC 5 (19.0 g) and minimum in JG 315 (16.8 g).

#### 4.1.1.7 Days to maturity

Among the lines JG 11 (92 days) was earliest to mature followed by A-1 (99 days) whereas, JAKI 9218 (102 days) was late maturing. The tester JG 315 (97 days) was early maturing followed by HC 5 (102 days) and JG 24 (102 days) which are on par with each other.

### 4.1.2 Mean performance of crosses

Mean performance of crosses is presented under the following heads (Table. 3).

#### 4.1.2.1 Days to 50 *per cent* flowering

Among nine hybrids evaluated, the crosses A-1 × HC 5 and JG 11 × HC 5 (34.5 days) were earliest to flower followed by JG 11 × JG 315 and JG 11 × JG 24 (36.0 days) which are on par with one another. Contrary to this, JAKI 9218 × JG 24 (38.0 days), took maximum number of days for 50 *per cent* flowering.

#### 4.1.2.2 Plant height (cm)

Maximum plant height of 42.40 cm was recorded by the cross A-1 × HC 5 which differed significantly from all other crosses. On the other hand, lowest plant height was recorded by the cross JAKI 9218 × JG 315 (35.73 cm), followed by JAKI 9218 × JG 24 (37.07 cm), JAKI 9218 × HC 5 (37.6 cm) which are on par with each other.

#### 4.1.2.3 Number of primary branches

Number of primary branches among cross combination was higher in A-1 × HC 5 (11.0) which differed significantly from all other crosses. On the other hand, lowest number of primary branches was possessed by the cross JAKI 9218 × JG 315 (6.9), followed by JG 11 × JG 315 (7.5) and A-1 × JG 315 (7.8) which are on par with each other.

#### 4.1.2.4 Number of pods plant$^{-1}$

The cross JG 11 × HC 5 recorded highest number of pods plant$^{-1}$ (88.4). On the other hand, lowest number of pods plant$^{-1}$ (44.5) was observed in the cross JG 11 × JG 315 (44.5), which differed significantly from all other crosses.

#### 4.1.2.5 Seed yield plant$^{-1}$ (g)

Among 9 hybrids evaluated the cross JG 11 × JG 24 recorded highest seed yield plant$^{-1}$ (24.3 g) which differed significantly from all other crosses. On the other hand, lowest seed yield plant$^{-1}$ of (10.8 g) was observed in the cross JG 11 × JG 315.

#### 4.1.2.6 100 seed weight (g)

Maximum 100 seed weight (28.9 g) was exhibited by the cross JG 11 × JG 24 which differed significantly from all other crosses while lowest 100 seed weight (19.5 g) was noticed in the hybrid JG 11 × JG 315, followed by A-1 × JG 315 (20.3 g) and A-1 × HC 5 (21.1 g) which are on par with each other.

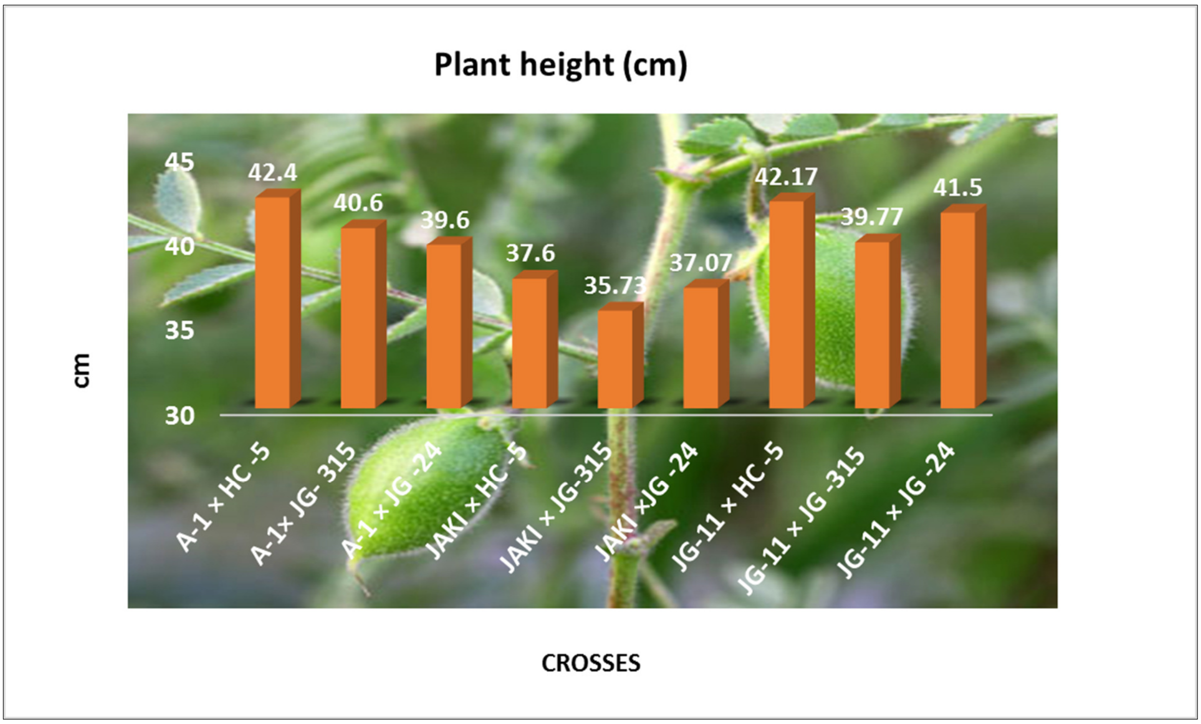


**Fig. 8: Mean performance of crosses with respect to plant height (cm)**

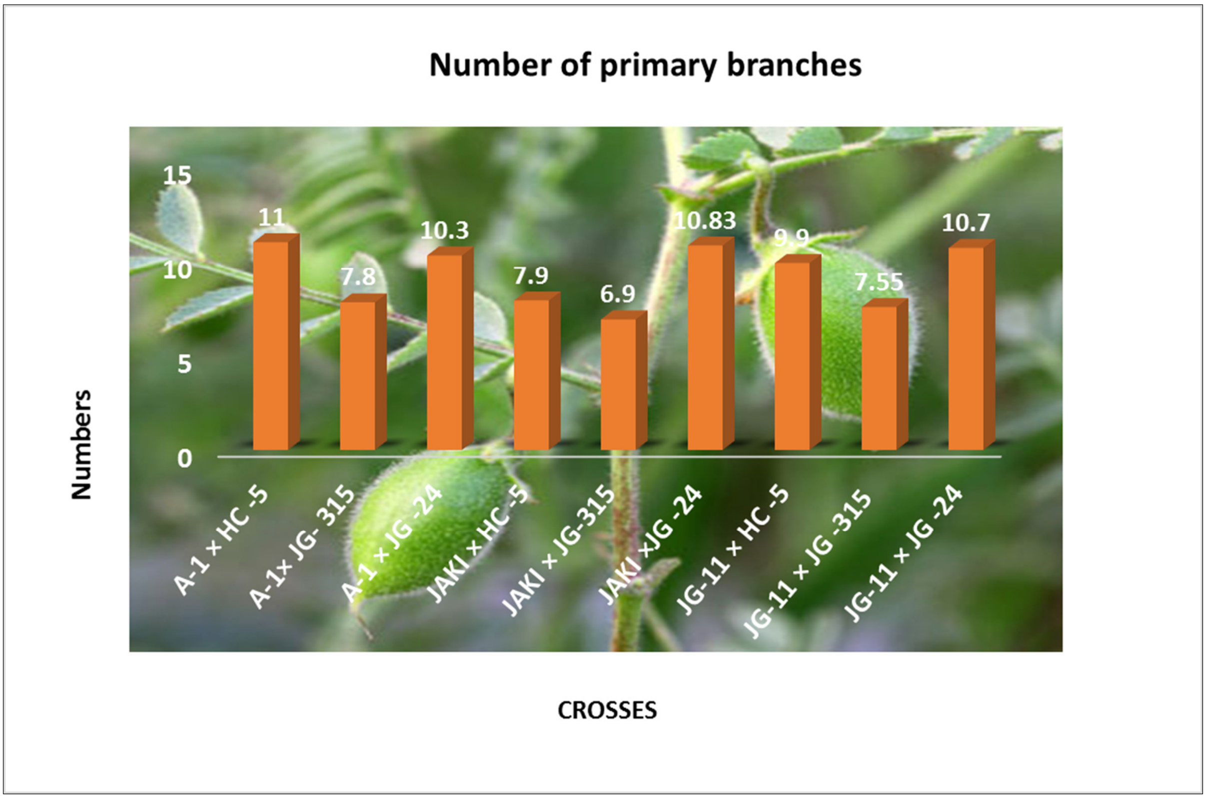


**Fig. 9: Mean performance of crosses with respect to number of primary branches**

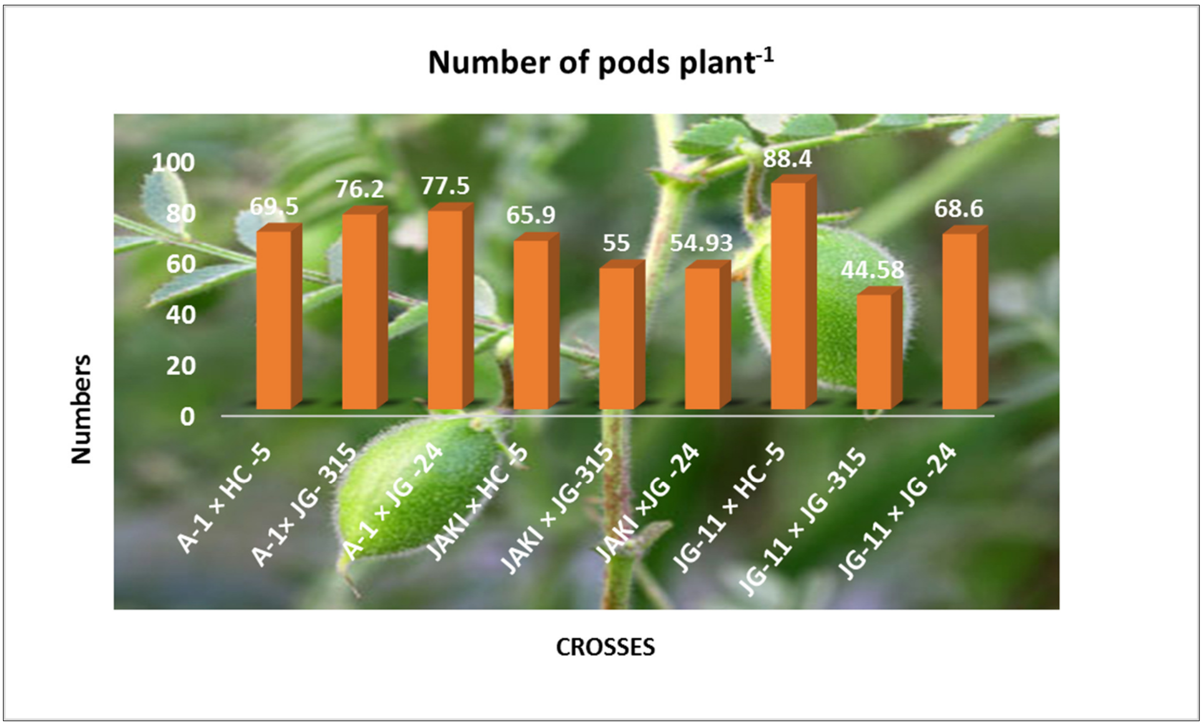


**Fig. 10: Mean performance of crosses with respect to number of pods plant$^{-1}$**

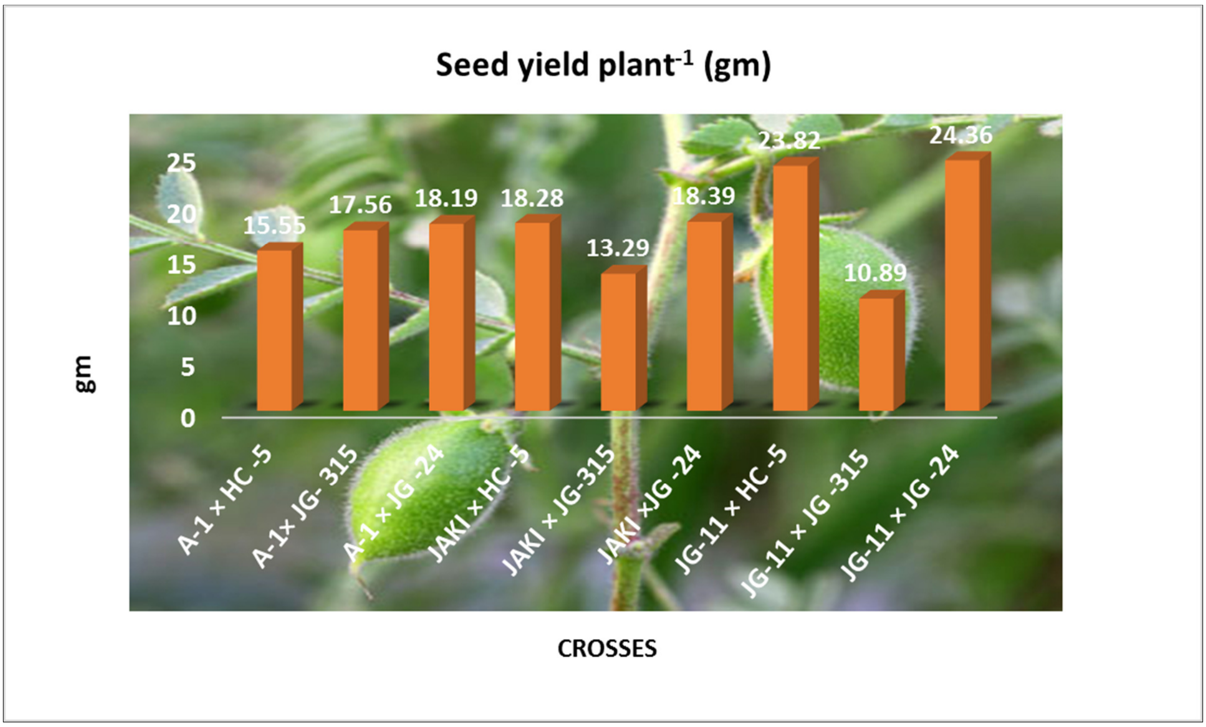


**Fig. 11: Mean performance of crosses with respect to seed yield plant$^{-1}$**

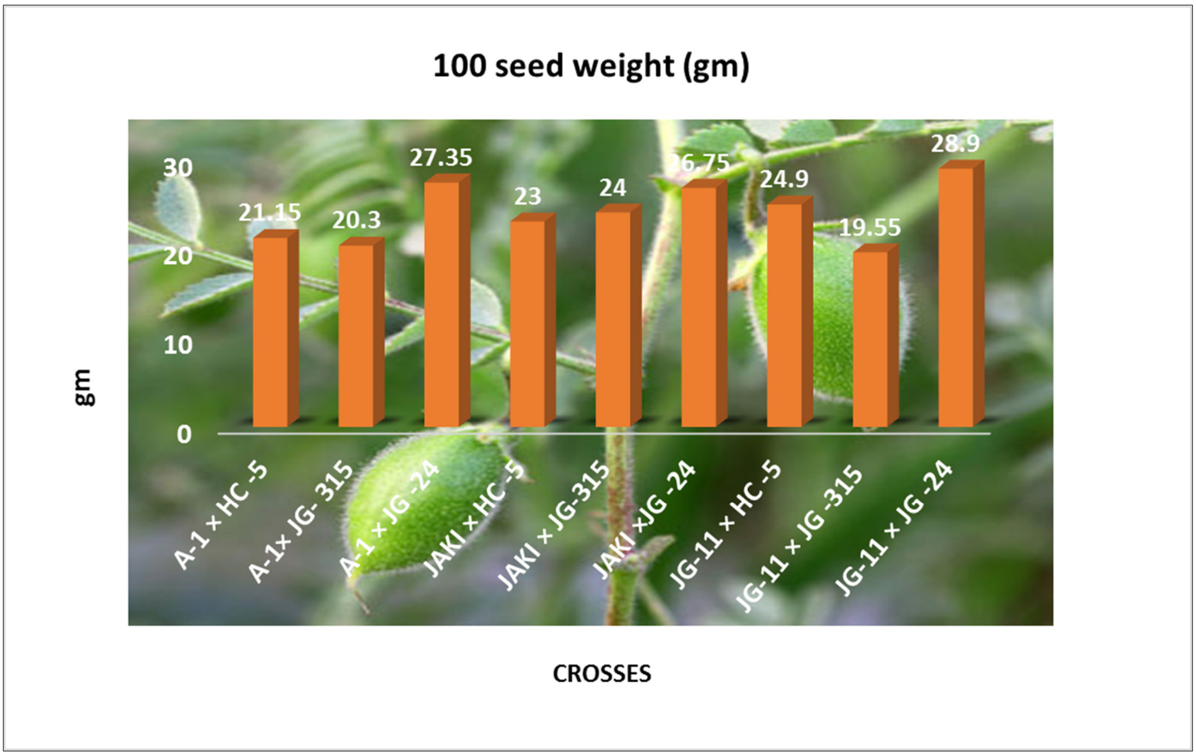


**Fig. 12: Mean performance of crosses with respect to 100 seed weight (g)**

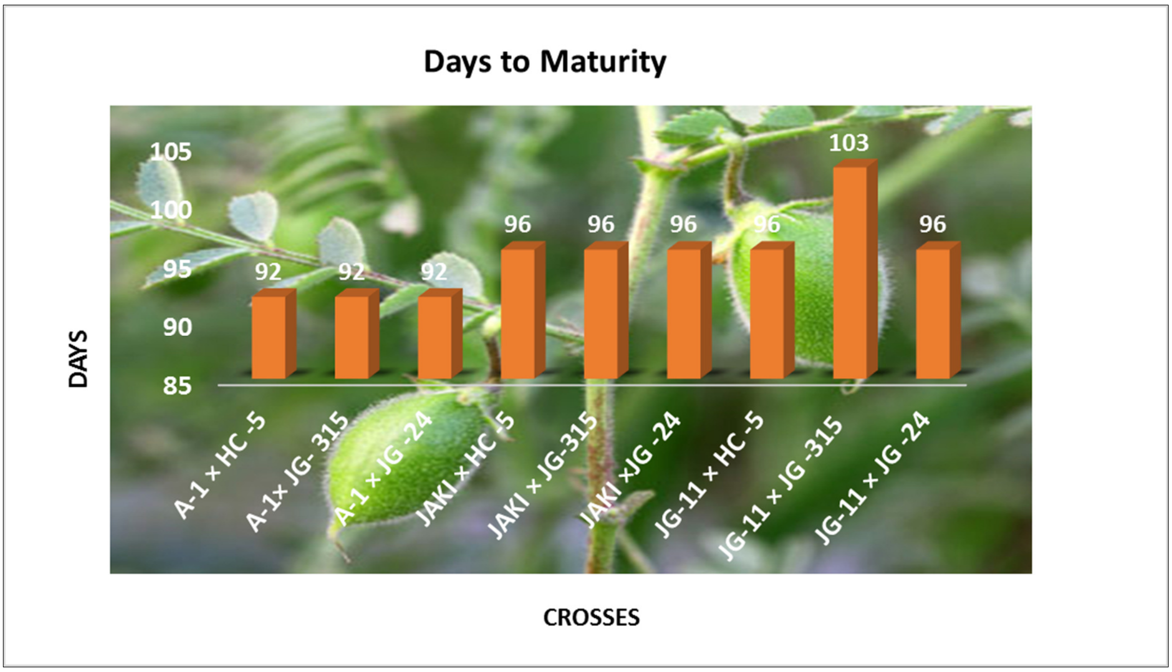


**Fig. 13: Mean performance of crosses with respect to days to maturity**

**Table 3. Mean performance of chickpea crosses in respect of grain yield and its attributing traits**

| Hybrids | Days to 50% flowering | Plant height (cm) | Number of primary branches | Number of pods plant$^{-1}$ | Seed yield plant$^{-1}$ (g) | 100 seed weight (g) | Days to maturity |
|---|---|---|---|---|---|---|---|
| A-1 × HC -5 | 34.50 | 42.40 | 11.00 | 69.50 | 15.55 | 21.15 | 92.00 |
| A-1× JG- 315 | 37.00 | 40.60 | 7.80 | 76.20 | 17.56 | 20.30 | 92.00 |
| A-1 × JG -24 | 37.50 | 39.60 | 10.30 | 77.50 | 18.19 | 27.35 | 92.00 |
| JAKI × HC -5 | 37.00 | 37.60 | 7.90 | 65.90 | 18.28 | 23.00 | 96.00 |
| JAKI × JG-315 | 36.50 | 35.73 | 6.90 | 55.00 | 13.29 | 24.00 | 96.00 |
| JAKI ×JG -24 | 38.00 | 37.07 | 10.83 | 54.93 | 18.39 | 26.75 | 96.00 |
| JG-11 × HC -5 | 34.50 | 42.17 | 9.90 | 88.40 | 23.82 | 24.90 | 96.00 |
| JG-11 × JG -315 | 36.00 | 39.77 | 7.55 | 44.58 | 10.89 | 19.55 | 103.00 |
| JG-11 × JG -24 | 36.00 | 41.50 | 10.70 | 68.60 | 24.36 | 28.90 | 96.00 |
| S.Em.± | 0.64 | 2.12 | 1.27 | 10.89 | 2.31 | 0.85 | 1.97 |
| C.D @ P= 0.05 | 1.94 | 6.41 | 3.84 | 5.60 | 6.97 | 2.58 | 5.94 |
| C.V.% | 2.4 | 6.9 | 3.8 | 16.2 | 14.7 | 5.1 | 2.8 |

#### 4.1.2.7 Days to maturity

A range of variability for this trait was observed among the crosses and ranged from 92.0 to 103.0 days. Among the crosses A-1 × HC 5, A-1 × JG 315, A-1 × JG 24 were earliest to mature (92.0 days), whereas the cross JG 11 × JG 315 (103 days) was late maturing which differed significantly from all other crosses.

## 4.2 Analysis of variance for seed yield and its attributing traits

The mean sum of squares for seed yield and yield attributing traits is presented in the Table 4. Significant difference was observed among the parents and crosses for all the characters except number of pods plant$^{-1}$. Parents differed significantly for all the characters except number of primary branches, number of pods plant$^{-1}$ and seed yield plant$^{-1}$. The crosses exhibited significant differences in respect of all the characters except plant height, number of primary branches and number of pods plant$^{-1}$. The mean sum of squares of parents *vs* crosses was significant for all the characters indicating presence of heterosis for all the traits.

## 4.3 Analysis of variance for combining ability

Mean sum of squares for seed yield and its attributing traits for lines, testers and lines × testers, is presented in Table 5. The lines exhibited significant differences for all the characters except days to 50 *per cent* flowering, number of primary branches, number of pods plant$^{-1}$ and seed yield plant$^{-1}$.

Mean sum of squares for testers was significant for all the characters except plant height, number of pods plant$^{-1}$ and seed yield plant$^{-1}$. However, line × tester interaction was significant for seed yield plant$^{-1}$, 100 seed weight and days to maturity.

## 4.4 Combining ability effects and gene action

### 4.4.1 General combining ability effects

Estimates of general combining ability (gca) effects of parents (lines and testers) are depicted in Table 6 and 7. The results of the same are presented below character wise.

#### 4.4.1.1 Days to 50 *per cent* flowering

Among the lines JG 11 showed significant negative gca effect (-0.83) which is desirable whereas JAKI 9218 exhibited highest positive and significant gca effect (0.83). On the other hand, among the testers HC 5 expressed significant negative gca effect (-1.00) which is desirable whereas JG 24 showed highest positive and significant gca effect (0.83) but in undesirable direction.

**Table 4. Analysis of variance for seed yield and its attributing traits in parents and crosses of chickpea**

| Source of variations | df | Mean sum of squares | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Days to 50% flowering | Plant height (cm) | Number of primary branches | Number of pods plant$^{-1}$ | Seed yield plant$^{-1}$ (g) | 100 Seed weight (g) | Days to maturity |
| Replication | 1 | 0.83 | 1.83 | 6.68 | 2887.39 | 325.64 | 1.58 | 0.53 |
| Parents and Crosses | 14 | 21.77** | 61.57** | 11.5* | 498.01 | 44.36** | 45.8** | 31.39** |
| Parents | 5 | 45.283** | 61.03** | 1.42 | 286.25 | 8.37 | 91.57** | 32.00** |
| Crosses | 8 | 3.0* | 11.10 | 5.37 | 363.68 | 38.29* | 21.55** | 23.55** |
| Parent vs Crosses | 1 | 54.45** | 467.97** | 110.95** | 2631.46** | 272.86** | 10.90* | 91.02** |
| Error | 14 | 0.83 | 9.43 | 3.48 | 252.72 | 11.22 | 1.36 | 4.81 |

*Significant @ P = 0.05 **Significant @ P = 0.01

**Table 5. Analysis of variance for combining ability in respect of seed yield and its attributing traits in parents and crosses of chickpea**

| Source of variations | df | Mean sum of squares | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Days to 50% flowering | Plant height (cm) | Number of primary branches | Number of pods plant$^{-1}$ | Seed yield plant$^{-1}$ (g) | 100 seed weight (g) | Days to maturity |
| Replication | 1 | 0.83 | 1.83 | 6.68 | 2887.39 | 325.64 | 1.58 | 0.53 |
| Parents and Crosses | 14 | 21.77** | 61.57** | 11.5* | 498.01 | 44.36** | 45.8** | 31.39** |
| Lines | 2 | 4.16 | 35.51** | 2.14 | 374.88 | 16.12** | 5.04 | 61.55** |
| Testers | 2 | 5.16** | 6.32 | 15.98* | 384.74 | 70.24 | 65.37* | 10.88** |
| Line × Tester | 4 | 1.33 | 1.29 | 1.69 | 347.55 | 33.40** | 7.90** | 10.88** |
| Error | 14 | 0.83 | 9.43 | 3.48 | 252.72 | 11.22 | 1.36 | 4.81 |

*Significant @ P = 0.05 **Significant @ P = 0.01

#### 4.4.1.2 Plant height (cm)

The line JG 11 recorded highest positive and significant gca effect (1.54) while the line JAKI 9218 exhibited negative significant gca effect (-2.80) and A-1 showed non significant positive gca effect. There were no significant gca effects observed among testers.

#### 4.4.1.3 Number of primary branches

Among the lines, only A-1 exhibited significant positive gca effect (0.49) whereas the line JAKI 9218 showed negative and non significant gca effect and non significant positive gca effect was observed in JG 11. Among testers, JG 315 showed significant negative gca effect (-1.79) whereas HC 5 (0.39) and JG 24 (1.40) recorded non significant positive gca effects.

#### 4.4.1.4 Number of pods plant$^{-1}$

For number of pods plant$^{-1}$, there were no significant gca effects among lines. The line A-1 (7.66), JG 11 (0.45) showed non significant positive gca effects whereas the line JAKI 9218 showed non significant negative gca effect. Among testers there were no significant gca effects. The tester JG 315 exhibited negative non significant gca effect. Whereas HC 5 (7.86) and JG 24 (0.27) exhibited positive non significant gca effect.

#### 4.4.1.5 Seed yield plant$^{-1}$ (g)

Among lines JG 11 exhibited highest positive and significant gca effect (1.87) where as A-1 (-0.71) and JAKI 9218 (-1.16) showed non significant negative gca effect. On the other hand, among the testers JG 315 showed negative significant gca effect (-3.90) and the tester JG 24 showed positive significant gca effect (2.49).

#### 4.4.1.6 100 seed weight (g)

Among lines JAKI 9218 showed highest positive significant gca effect (0.59) whereas A-1 showed negative non significant gca effect (-1.05) and JG 11 showed positive non significant gca effect (0.46). Among testers JG 24 exhibited highest positive significant gca effect (3.67), significant negative gca effect was recorded in JG 315 (-2.70).

### 4.4.2 Overall general combining ability status of parents

Since different traits are positively and negatively correlated, it is usual to find, for a particular parent, gca in the desirable direction for some characters and in undesirable direction for the others. Hence, it becomes important to decide whether a parent is a good combiner across all the character or not. In this context, the method proposed by Arunachalam and Bandyopadyay (1979) with slight modification as suggested by Mohan Rao (2001) was used in the present investigation to determine the overall general combining ability status of a line or a tester across the traits. The results of the same are tabulated in table 8 and briefly presented below.

**Table 6. Estimates of general combining ability effects of lines for seed yield and its attributing traits**

| Lines | Days to 50% flowering | Plant height (cm) | Number of primary branches | Number of pods plant$^{-1}$ | Seed yield plant$^{-1}$ (g) | 100 seed weight (g) |
|---|---|---|---|---|---|---|
| A-1 | 0.00 | 1.26 | 0.49* | 7.66 | -0.71 | -1.05 |
| JAKI 9218 | 0.83* | -2.80* | -0.66 | -8.12 | -1.16 | 0.59* |
| JG 11 | -0.83* | 1.54** | 0.17 | 0.45 | 1.87** | 0.46 |
| S.Em.± | 0.36 | 1.15 | 0.90 | 6.56 | 1.41 | 0.50 |
| C.D @ P= 0.05 | 0.80 | 2.67 | 2.08 | 15.12 | 3.26 | 1.16 |
| C.D @ P= 0.01 | 1.16 | 3.89 | 3.03 | 22.01 | 4.74 | 1.69 |

**Table 7. Estimates of general combining ability effects of tester for seed yield and its attributing traits**

| Testers | Days to 50% flowering | Plant height (cm) | Number of primary branches | Number of pods plant$^{-1}$ | Seed yield plant$^{-1}$ (g) | 100 seed weight (g) |
|---|---|---|---|---|---|---|
| HC -5 | -1.00* | 1.11 | 0.39 | 7.86 | 1.40 | -0.97 |
| JG 315 | 0.16 | -0.90 | -1.79* | -8.14 | -3.90* | -2.70** |
| JG 24 | 0.83* | -0.21 | 1.40 | 0.27 | 2.49** | 3.67** |
| S.Em.± | 0.36 | 1.15 | 0.90 | 6.56 | 1.41 | 0.50 |
| C.D @ P= 0.05 | 0.80 | 2.67 | 2.08 | 15.12 | 3.26 | 1.16 |
| C.D @ P= 0.01 | 1.16 | 3.89 | 3.03 | 22.01 | 4.74 | 1.69 |

*Significant @ P = 0.05 **Significant @ P = 0.01

**Table 8. Over all general combining ability status of parents in Chickpea**

| Particulars | Total rank | Over all gca status |
|---|---|---|
| **Lines** | | |
| A-1 | 16 | H |
| JAKI 9218 | 12 | L |
| JG 11 | 14 | H |
| **Testers** | | |
| HC -5 | 13 | L |
| JG 315 | 11 | L |
| JG 24 | 18 | H |

Final norm for Lines : 14

Final norm for Testers : 14

H: Over all high combiner

L: Over all low combiner

The lines A-1 and JG 11 were high (H) overall general combiners. However the line, JAKI 9218, was low overall general combiner (Table 8). As far as testers were concerned, JG 24 was found to be high (H) overall general combiners. HC 5 and JG 315 was found to be low overall general combiner.

### 4.4.3 Specific combining ability effects

The estimates of specific combining ability (sca) effects of nine crosses for different attributes are presented in Table 9 and the results are presented below character wise.

#### 4.4.3.1 Days to 50 *per cent* flowering

Of the nine hybrids evaluated, only 3 hybrids manifested significant sca effects in the desirable direction. Highest negative sca effecet was recorded by the cross A-1 × HC-5 and JAKI 9218 × JG 315 (-8.3) which are on par with each other. However, highest positive significant sca effect was recorded by the cross JAKI 9218 × HC 5 (0.83).

#### 4.4.3.2 Plant height (cm)

In respect of this trait, the cross JG 11 × JG 24 manifested significant positive sca effect (0.56) whereas the hybrid A-1 × JG 24 showed significant negative sca effect (-1.05). All other 7 crosses exhibited non significant sca effect.

#### 4.4.3.3 Number of primary branches

The hybrid JAKI 9218 × HC 5 exhibited negative significant sca effect (-1.03) whereas all other eight hybrids showed non significant sca effects.

#### 4.4.3.4 Number of pods plant$^{-1}$

Of the nine hybrids, only JAKI 9218 × JG 24 showed significant negative sca effect. whereas all other eight hybrids showed non significant sca effects.

#### 4.4.3.5 Seed yield plant$^{-1}$ (g)

Among nine hybrids, four hybrids exhibited significant positive sca effect. The hybrid A-1 × JG 315 manifested highest positive significant sca effect (4.36) whereas JG 11 × HC 5 exhibited significant sca effect (2.72) and is statistically on par with that of JG 11 × JG 24 (2.17). The hybrid JAKI 9218 × JG 315 showed lowest positive significant sca effect (0.54).

**Table 9. Estimates of specific combining ability effects of crosses for seed yield and its attributing traits**

| Hybrids | Days to 50% flowering | Plant height (cm) | Number of primary branches | Number of pods plant$^{-1}$ | Seed yield plant$^{-1}$ (g) | 100 seed weight (g) |
|---|---|---|---|---|---|---|
| A-1 × HC -5 | -0.83* | 0.41 | 0.90 | -12.76 | -2.95 | -0.81 |
| A-1× JG- 315 | 0.50 | 0.63 | -0.10 | 9.94 | 4.36** | 0.07 |
| A-1 × JG -24 | 0.33 | -1.05* | -0.80 | 2.82 | -1.40 | 0.73 |
| JAKI × HC -5 | 0.83 | -0.31 | -1.03** | -0.57 | 0.22 | -0.61 |
| JAKI × JG-315 | -0.83* | -0.16 | 0.14 | 4.53 | 0.54* | 2.12* |
| JAKI ×JG -24 | 0.00 | 0.48 | 0.88 | -3.95* | -0.76 | -1.51 |
| JG-11 × HC -5 | 0.00 | -0.09 | 0.12 | 13.34 | 2.72** | 1.42 |
| JG-11 × JG -315 | 0.33 | -0.47 | -0.04 | -14.47 | -4.90 | -2.19* |
| JG-11 × JG -24 | -0.33 | 0.56** | -0.08 | 1.13 | 2.17** | 0.77 |
| S.Em.± | 0.60 | 2.00 | 1.56 | 11.36 | 2.45 | 0.87 |
| C.D @ P= 0.05 | 1.38 | 4.63 | 3.60 | 26.20 | 5.65 | 2.01 |
| C.D @ P= 0.01 | 2.01 | 6.73 | 5.25 | 38.13 | 8.22 | 2.93 |

*Significant @ P = 0.05 **Significant @ P = 0.01

#### 4.4.3.6 100 seed weight (g)

The cross combination JAKI 9218 × JG 315 (2.12) exhibited highly significant positive sca effect. Among all hybrids, JG 11 × JG 315 showed significant negative sca effect for 100 seed weight.

### 4.4.4 Proportional contribution of lines, testers and line × tester interaction

From the results presented in Table 10, it is evident that contribution of testers towards variation in the hybrids was higher for days to 50 *per cent* flowering (43.05 *per cent*), number of primary branches (74.31 *per cent*), seed yield plant$^{-1}$ (45.85 *per cent*), and 100 seed weight (75.82 *per cent*) when compared to lines and line × tester interaction. Whereas *per cent* contribution of line × tester interaction towards variation in the hybrids was higher for number of pods plant$^{-1}$ (47.78 *per cent*) as compared to that of lines and testers individually. *Per cent* contribution of lines towards variation in the crosses was higher for plant height (79.92 *per cent*) and for days to maturity (65.33 *per cent*). *per cent* contribution of line × tester interaction towards total variation was maximum in number of pods plant$^{-1}$.

## 4.5 Variance due to general and specific combining ability

The estimates of variance due to general combining ability (GCA), variance due to specific combining ability (SCA), ratio of GCA and SCA variance, additive variance (VA) and dominance variance (VD) in respect of all the seven characters studied are presented in Table 11.

The results clearly revealed that predominance of dominant genotypic variance for the traits days to 50 *per cent* flowering, number of pods plant$^{-1}$, seed yield plant$^{-1}$, 100 seed weight and days to maturity which results in heterotic behavior of $F_1$ hybrids over their parents.

The results shown that variance due to GCA was higher in plant height, number of primary branches, while variance due to SCA for days to 50 *per cent* flowering, number of pods plant$^{-1}$, seed yield plant$^{-1}$, 100 seed weight, and days to maturity when compared to that of variance due to GCA. The results clearly revealed the predominance of SCA variance for these traits.

**Table 10. Proportional contribution of lines, testers and line × tester interaction towards total variation in chickpea crosses.**

| Characters | Lines | Testers | Line × Tester analysis |
|---|---|---|---|
| Days to 50% flowering | 34.72% | 43.05% | 22.22% |
| Plant height (cm) | 79.92% | 14.23% | 5.84% |
| Number of primary branches | 9.96% | 74.31% | 15.71% |
| Number of pods $plant^{-1}$ | 25.76% | 26.44% | 47.78% |
| Seed yield $plant^{-1}$ (g) | 10.52% | 45.85% | 43.61% |
| 100 seed weight (g) | 5.84% | 75.82% | 18.33% |
| Days to maturity | 65.33% | 11.55% | 23.11% |

**Table 11. Variance due to general and specific combining ability for seed yield, and its attributing traits**

| Characters | Variance due to GCA | Variance due to SCA | GCA : SCA ratio | |
|---|---|---|---|---|
| Days to 50% flowering | 0.13 | 0.30 | 1 : 2.30 | |
| Plant height | 0.81 | -3.38 | 1 : 4.17 | |
| Number of primary branches | 0.30 | -1.60 | 1 : 5.33 | |
| Number of pods plant$^{-1}$ | 1.34 | 44.63 | 1 : 33.30 | |
| Seed yield plant$^{-1}$ | 0.40 | 10.69 | 1 : 26.72 | |
| 100 seed weight | 1.13 | 3.18 | 1 : 2.81 | |
| Days to maturity | 1.05 | 5.44 | 1 : 5.18 | |

### 4.6 Heterosis

#### 4.6.1 Standard heterosis and mid parent heterosis

The extent of heterosis over mid parent (MP) and standard check (SC) JG 11 expressed by nine crosses in respect of yield and yield attributing traits have been tabulated in Table 12 and briefly presented trait wise, while estimating the overall heterotic status of hybrids, mid parent heterosis values were used and hence discussed in the subsequent appropriate sections.

##### 4.6.1.1 Days to 50 *per cent* flowering

Among nine crosses, the cross JAKI 9218 × HC 5 exhibited highest significant negative mid parent heterosis (-16.38 *per cent*) in desirable direction followed by JG 11 × HC 5 (-12.11 *per cent*), A-1 × HC-5 (-12.10 *per cent*), JAKI 9218 × JG 24 (-10.59 *per cent*), JAKI 9218 × JG 315 (-9.88 *per cent*).Of the nine crosses, JAKI 9218 × JG 24 showed maximum significant positive heterosis (7.04 *per cent*) over standard check JG 11 followed by A-1 × JG 24 (5.63 *per cent*).

##### 4.6.1.2 Plant height (cm)

Seven out of nine crosses expressed significant negative heterosis over mid parent. Of which, the cross JAKI 9218 × JG 24 exhibited highest significant negative mid parent heterosis (-29.46 *per cent*) followed by JAKI 9218 × HC 5 (-27.48 *per cent*), JAKI 9218 × JG 315 (-24.21 *per cent*), A-1 × JG 24 (-16.10 *per cent*), JG 11 × JG 24 (-15.91 *per cent*), JG 11 × HC 5 (-13.33 *per cent*), and A- 1 × HC 5 (-8.82 *per cent*). Contrary to this, three crosses JAKI 9218 × JG 315 (-22.32 *per cent*), and JAKI 9218 × JG 24 (-19.42 *per cent*) and JAKI 9218 × HC 5(-18.26 *per cent*) recorded less than 15 *per cent* significant negative heterosis over the standard check JG 11.

##### 4.6.1.3 Number of primary branches

Four crosses out of nine, showed significant positive mid parent heterosis for this trait *viz.*, JG 11 × JG 24 (125.26 *per cent*), JAKI 9218 × JG 24 (112.35 *per cent*), JG 11 × HC 5 (100.00 *per cent*), and A- 1 × HC 5 (80.33 *per cent*) recorded more than 80 *per cent* heterosis. Contrary to this, 5 crosses exhibited significant positive heterosis over standard check JG 11, which are A- 1 × HC 5 (175.00 *per cent*), JAKI 9218 × JG 24 (170.75 *per cent*), JG 11 × JG 24 (167.50 *per cent*), A-1 × JG 24 (157.50 *per cent*), and JG 11 × HC 5 (147.50 *per cent*) these recorded more than 100 *per cent* heterosis.

##### 4.6.1.4 Number of pods plant$^{-1}$

Only one out of nine crosses, *viz.,* JG 11 × HC 5 (108.49 *per cent*) recorded significant heterosis over mid parent and all the remaining hybrids exhibited non significant positive heterosis whereas, one hybrid showed non significant negative heterosis. On the other hand, 3 crosses exhibited significant positive standard heterosis over the check JG 11, which are JG 11 × HC 5 (170.34 *per cent*), A-1 × JG 24 (137.00 *per cent*), and A-1 × JG 315 (133.03 *per cent*) these recorded more than 100 *per cent* heterosis.

**Table 12. Estimates of mid parent heterosis and standard heterosis (over check JG 11) for seed yield and its attributing traits in chickpea**

| Crosses | Days to 50% flowering | | Plant height | | Number of primary branches | | Number of pods plant$^{-1}$ | | Seed yield plant$^{-1}$ | | 100 seed weight | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MP | SC | MP | SC | MP | SC | MP | SC | MP | SC | MP | SC |
| A-1 × HC -5 | -12.10** | -2.82 | -8.82 | -7.83 | 80.33* | 175.00* | 23.12 | 112.54 | 26.27 | 88.03 | 3.55 | -21.38** |
| A-1× JG- 315 | 4.23 | 4.23 | -2.87 | -11.74 | 34.48 | 95.00 | 24.92 | 133.03* | 31.14 | 112.33* | 5.18 | -24.54** |
| A-1 × JG -24 | 0.00 | 5.63* | -16.10* | -13.91 | 74.58 | 157.50* | 51.66 | 137.00* | 31.38 | 119.95* | -3.10 | 1.67 |
| JAKI × HC -5 | -16.38** | 4.23 | -27.48** | -18.26* | 49.06 | 97.50 | 47.10 | 101.53 | 89.53 | 121.04* | 24.66* | -14.50* |
| JAKI × JG-315 | -9.88** | 2.82 | -24.21** | -22.32** | 38.00 | 72.50 | 11.45 | 68.20 | 24.00 | 60.74 | 38.53* | -10.78* |
| JAKI ×JG -24 | -10.59** | 7.04* | -29.46** | -19.42* | 112.35* | 170.75* | 39.25 | 67.99 | 64.53* | 122.33* | 1.90 | -0.56 |
| JG-11 × HC -5 | -12.11** | -2.82 | -13.33* | -8.33 | 100.00* | 147.50* | 108.49* | 170.34* | 128.82* | 188.03* | 9.57 | -7.43 |
| JG-11 × JG -315 | 1.41 | 1.41 | -9.50 | -13.53 | 62.37 | 88.75 | -5.06 | 36.31 | -5.18 | 31.68 | -9.49 | -27.32** |
| JG-11 × JG -24 | -4.00 | 1.41 | -15.91* | -9.78 | 125.26* | 167.50* | 85.16 | 109.79 | 104.02** | 194.56* | -5.32 | 7.43 |
| S.Em.± | 0.73 | 0.84 | 2.45 | 2.83 | 1.91 | 2.21 | 13.91 | 16.07 | 3.00 | 3.46 | 1.07 | 1.23 |
| C.D @ P= 0.05 | 1.69 | 1.95 | 5.67 | 6.54 | 4.42 | 5.10 | 32.09 | 37.06 | 6.92 | 7.99 | 2.46 | 2.85 |
| C.D @ P= 0.01 | 2.46 | 2.85 | 8.25 | 9.52 | 6.43 | 7.42 | 46.70 | 53.92 | 10.07 | 11.62 | 3.59 | 4.14 |

*Significant @ P = 0.05 **Significant @ P = 0.01

#### 4.6.1.5 Seed yield plant$^{-1}$ (g)

Of the nine crosses, the cross JG 11 × HC 5 expressed highest significant positive mid parent heterosis (128.82 *per cent*) followed by JG 11 × JG 24 (104.02 *per cent*), JAKI 9218 × HC-5 (59.53 *per cent*) and JAKI 9218 × JG 24 (64.53 *per cent*). Six of the nine crosses showed significant positive standard heterosis over the check JG 11 among them JG 11 × JG 24 (194.56 *per cent*) recorded maximum heterosis followed by JG 11 × HC 5(188.03 *per cent*), JAKI 9218 × JG 24 (122.33 *per cent*), JAKI 9218 × HC 5 (121.04 *per cent*), A-1 × JG 24 (119.95 *per cent*) and A-1 × JG 315 (112.33 *per cent*).

#### 4.6.1.6 100 seed weight (g)

Out of nine crosses, two crosses showed significant positive heterosis. JAKI 9218 × JG 315 (38.53 *per cent*) exhibited highest significant positive mid parent heterosis followed by JAKI 9218 × HC 5 (24.66 *per cent*). On the other hand JG 11 × JG 315 (-27.32 *per cent*) manifested highest significant negative standard heterosis over the check JG 11 followed by A-1 × JG 315 (-24.54 *per cent*), A-1 × HC 5 (-21.38 *per cent*), JAKI 9218 × HC 5 (-14.50 *per cent*) and JAKI 9218 × JG 315 (-10.78 *per cent*).

### 4.6.2 Overall Specific combining ability and heterotic status of crosses

In addition to determining the overall general combining ability status of parents it becomes important also to determine the overall sca and heterotic status of the crosses across yield and yield attributing traits. Hence, using the data explained under materials and methods under the overall sca and heterotic status of each cross was determined and results of the same are presented in Table 13.

It is clear that five of the nine crosses had high over all specific combining ability status across the traits studied and remaining four belongs to overall low specific combination. Five hybrids manifested a high (H) overall heterotic status and the remaining four crosses expressed low (L) overall heterotic status across the traits.

**Table 13. Overall sca & heterotic status of Chickpea crosses**

| **Lines** | | A-1 | | | | JAKI- 9218 | | | | JG-11 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (H) | | | | (L) | | | | (H) | | | |
| **Testers** | | Sca status | | Heterotic Status | | Sca status | | Heterotic status | | Sca Status | | Heterotic status | |
| HC -5 | (L) | 30 | L | 34 | L | 26 | L | 46 | H | 48 | H | 46 | H |
| JG 315 | (L) | 37 | H | 24 | L | 52 | H | 31 | L | 20 | L | 13 | L |
| JG 24 | (H) | 36 | H | 38 | H | 31 | L | 44 | H | 35 | H | 39 | H |

Final norm = 35

(H): Over all high general combiner

(L): Over all low general combiner

H: Over all high specific combination

L: Over all low specific combination

## 4.7 Genetic variability parameters

Amount of genetic variability in the $F_2$ population of four crosses ($C_1$=A-1 × JG 315, $C_2$=A-1 × HC 5, $C_3$= JG 11 × JG 24, $C_4$ = JAKI 9218 × HC 5) was estimated by mean, absolute range and phenotypic coefficient of variation (PCV) that have been presented in Table 14. Therefore crosses were selected based on the population size in the field and observation was recorded in randomly selected plants.

### 4.7.1 Days to 50 *per cent* flowering

Days to 50 *per cent* flowering in the four crosses *viz.*, $C_1$, $C_2$, $C_3$, $C_4$ expressed a mean value of 41.8, 44.4, 39.4, 38.8 and ranged from 37 to 47, 41 to 49, 36 to 43, and 36 to 42, respectively the estimates of PCV was low in all the four crosses ($C_1$= 4 *per cent*, $C_2$= 3.32 *per cent*, $C_3$= 4.76 *per cent*, and $C_4$= 4.06 *per cent*).

### 4.7.2 Plant height (cm)

In the four crosses *viz.*, $C_1$, $C_2$, $C_3$, $C_4$ for Plant height exhibited a mean value of 36.1, 40.37, 37.29, 35.62 and ranged between 21 to 61, 19 to 69, 18 to 67 and 20 to 57, respectively the estimates of PCV were moderate in two crosses ($C_1$= 18.96 *per cent* and $C_4$= 17 *per cent*) and high in two crosses ($C_2$= 20.58 *per cent*, $C_3$= 21.42 *per cent*).

### 4.7.3 Number of primary branches

Number of primary branches in the four crosses *viz.,* $C_1$, $C_2$, $C_3$, $C_4$ displayed a mean value of 5.54, 5.56, 4.06, and 5.16 varied from 1 to 15, 1 to 15, 1 to 11, and 2 to 10, respectively the estimates of PCV was high in all the four crosses ($C_1$= 44 *per cent*, $C_2$= 40.82 *per cent*, $C_3$= 38.66 *per cent*, and $C_4$= 33.52 *per cent*).

### 4.7.4 Number of pods plant$^{-1}$

In the four crosses *viz.*, $C_1$, $C_2$, $C_3$, $C_4$ for number of pods plant$^{-1}$ exhibited a mean value of 74.12, 76.59, 54.93, 83.37 and ranged from 8 to 250, 10 to 260, 13 to 186 and 10 to 250, respectively the estimates of PCV were high in all the four crosses ($C_1$= 70 *per cent*, $C_2$= 65.06 *per cent*, $C_3$= 53.01 *per cent* and $C_4$= 48.31 *per cent*).

### 4.7.5 Seed yield plant$^{-1}$ (g)

Seed yield plant$^{-1}$ showed a mean value of 16.57, 16.20, 19.03, and 25.99 ranged from 2 to 60.8, 2.2 to 45.7, 1.2 to 69.4 and 5.1 to 73.9, respectively in the four crosses. The estimates of PCV was high in all the four crosses ($C_1$= 65 *per cent*, $C_2$= 59.22 *per cent*, $C_3$= 54.07 *per cent*, and $C_4$= 44.13 *per cent*).

**Table 14. Estimates of mean and variance for seed yield and yield attributing traits in $F_2$ population of the four crosses**

| | | | Absolute range | | |
|---|---|---|---|---|---|
| Characters | Crosses | Mean±SE | Maximum | Minimum | PCV(%) |
| Days to 50% flowering | $C_1$ | 41.81±0.13 | 37 | 47 | 4 |
| | $C_2$ | 44.46±0.10 | 41 | 49 | 3.32 |
| | $C_3$ | 39.43±0.15 | 36 | 43 | 4.76 |
| | $C_4$ | 38.83±0.12 | 36 | 42 | 4.06 |
| Plant height (cm) | $C_1$ | 36.18±0.43 | 21 | 61 | 18.96 |
| | $C_2$ | 40.37±0.56 | 19 | 69 | 20.58 |
| | $C_3$ | 37.29±0.63 | 18 | 67 | 21.42 |
| | $C_4$ | 35.62±0.48 | 20 | 57 | 17 |
| Number of primary branches | $C_1$ | 5.54±0.15 | 1 | 15 | 44 |
| | $C_2$ | 5.56±0.15 | 1 | 15 | 40.82 |
| | $C_3$ | 4.06±0.12 | 1 | 11 | 38.66 |
| | $C_4$ | 5.16±0.14 | 2 | 10 | 33.52 |
| Number of pods plant$^{-1}$ | $C_1$ | 74.12±3.29 | 8 | 250 | 70 |
| | $C_2$ | 76.59±3.41 | 10 | 260 | 65.06 |
| | $C_3$ | 54.93±2.31 | 13 | 186 | 53.01 |
| | $C_4$ | 83.37±3.25 | 10 | 250 | 48.31 |
| Seed yield plant$^{-1}$ (g) | $C_1$ | 16.57±0.68 | 2 | 60.8 | 65 |
| | $C_2$ | 13.76±0.55 | 2.2 | 45.7 | 59.22 |
| | $C_3$ | 19.03±0.81 | 1.2 | 69.4 | 54.07 |
| | $C_4$ | 25.99±0.92 | 5.1 | 73.9 | 44.13 |
| 100 Seed weight (g) | $C_1$ | 21.21±0.37 | 4.4 | 43.6 | 27.9 |
| | $C_2$ | 16.20±0.26 | 7.1 | 45.6 | 23.88 |
| | $C_3$ | 27.63±0.39 | 2.8 | 40.2 | 17.77 |
| | $C_4$ | 25.9±0.37 | 15.1 | 73.9 | 18.1 |
| Days to maturity | $C_1$ | 101.08±0.21 | 95 | 109 | 3.41 |
| | $C_2$ | 94.58±0.12 | 91 | 98 | 1.96 |
| | $C_3$ | 98.50±0.22 | 94 | 104 | 2.88 |
| | $C_4$ | 96.34±0.10 | 15.1 | 44.3 | 1.32 |

#### 4.7.6 100 seed weight (g)

100 seed weight exerted a mean value of 21.21, 16.20, 27.63, and 25.9 ranged from 4.4 to 43.6, 7.1 to 45.6, 2.8 to 40.2 and 15.1 to 73.9, respectively in the four crosses. The estimates of PCV is high in two crosses ($C_1$= 27.9 *per cent*, $C_2$= 23.88 *per cent*) and moderate in two crosses ($C_3$= 17.77 *per cent*, $C_4$= 18.1 *per cent*).

#### 4.7.7 Days to maturity

In the four crosses *viz*., $C_1$, $C_2$, $C_3$, $C_4$ for days to maturity displayed a mean value of 101.08, 94.58, 98.50, 96.34 and varied from 95 to 109, 91 to 98, 94 to 104 and 15.1 to 44.3, respectively. The estimates of PCV were low in all the four crosses ($C_1$= 3.41 *per cent*, $C_2$= 1.96 *per cent*, $C_3$= 2.88 *per cent* and $C_4$= 1.32 *per cent*).

### 4.8 Correlation studies in $F_2$ population of four crosses

Phenotypic correlation coefficients for seed yield and yield contributing traits for four crosses ($C_1$=A-1 × JG 315, $C_2$=A-1 × HC 5, $C_3$= JG 11 × JG 24, $C_4$ = JAKI 9218 × HC 5) was estimated in $F_2$ population and results are presented in Table 15.

#### 4.8.1 Correlation coefficient of seed yield plant$^{-1}$ with yield attributing characters

Seed yield plant$^{-1}$ showed positive significant association with plant height (0.4041, 0.3021, 0.5464, 0.2904) and number of pods plant$^{-1}$ (0.8522, 0.6214, 0.5533, 0.2599) in all the four crosses respectively.

Seed yield plant$^{-1}$ exhibited significantly positive association with number of primary branches in the three crosses *viz*., A-1 × JG 315 (0.4329), A-1 × HC 5 (0.3551) and JG 11 × JG 24 (0.5709).

Seed yield plant$^{-1}$ displayed significant positive association with 100 seed weight in A-1 × HC 5 (0.2775), JG 11 × JG 24 (0.1972) and JAKI 9218 × HC 5 (0.3274) respectively. It also showed significant positive association with days to maturity in the cross JG 11 × JG 24 (0.1894). It also showed positive association with days to 50 *per cent* flowering but it was not significant.

#### 4.8.2 Character association studied among yield components in four crosses

The crosses A-1 × JG 315, A-1 × HC 5, JG 11 × JG 24, for plant height exhibited significant positive association at 0.01 probability level with number of primary branches (0.2049, 0.4216, 0.3157), significant positive association of plant height with 100 seed weight was observed in the cross JG 11 × JG 24 (0.2093).

The two crosses A-1 × JG 315 (-0.1534) and A-1 × HC 5 (-0.1351) for number of pods plant$^{-1}$ exerted significant negative association with 100 seed weight, whereas JG 11 × JG 24 (0.1697) showed significant positive association with days to maturity.

**Table 15. Estimates of phenotypic correlation coefficient for seed yield and its contributing traits in $F_2$ population of the four crosses**

| Traits | Crosses | Days to 50% flowering | Plant height (cm) | Number of primary branches | Number of pods plant$^{-1}$ | 100 Seed weight (g) | Days to maturity | Seed yield plant$^{-1}$ (g) |
|---|---|---|---|---|---|---|---|---|
| Days to 50% flowering | $C_1$ | **1.0000** | -0.0446 | -0.0962 | -0.0577 | 0.0932 | -0.0345 | -0.0444 |
| | $C_2$ | **1.0000** | -0.1190 | -0.1086 | -0.0045 | -0.0276 | -0.1283** | -0.0246 |
| | $C_3$ | **1.0000** | 0.1455 | -0.0584 | -0.0258 | 0.1502 | 0.0178 | 0.0576 |
| | $C_4$ | **1.0000** | -0.0204 | -0.1114 | -0.0284 | -0.0612 | 0.1026 | -0.0779 |
| Plant height | $C_1$ | | **1.0000** | 0.2049 ** | 0.4284 ** | 0.0235 | 0.0187 | 0.4041** |
| | $C_2$ | | **1.0000** | 0.4216 ** | 0.4593 ** | -0.1181 | 0.1238 | 0.3021** |
| | $C_3$ | | **1.0000** | 0.3157 ** | 0.2850 ** | 0.2093 ** | 0.039 | 0.5464** |
| | $C_4$ | | **1.0000** | 0.1340 | 0.2230 ** | -0.1056 | -0.0673 | 0.2904** |
| Number of primary branches | $C_1$ | | | **1.0000** | 0.5097 ** | -0.0918 | 0.1183 | 0.4329** |
| | $C_2$ | | | **1.0000** | 0.5266 ** | -0.0855 | 0.0835 | 0.3551** |
| | $C_3$ | | | **1.0000** | 0.3773 ** | -0.0204 | 0.0769 | 0.5709** |
| | $C_4$ | | | **1.0000** | 0.3363 ** | -0.1520 | -0.0812 | 0.2091 |
| Number of pods plant$^{-1}$ | $C_1$ | | | | **1.0000** | -0.1534 * | 0.0266 | 0.8522** |
| | $C_2$ | | | | **1.0000** | -0.1351 * | 0.0283 | 0.6214** |
| | $C_3$ | | | | **1.0000** | 0.0056 | 0.1697* | 0.5533** |
| | $C_4$ | | | | **1.0000** | -0.1021 | -0.1314 | 0.2599** |

**(Contd….)**

| Traits | Crosses | Days to 50% flowering | Plant height (cm) | Number of primary branches | Number of pods plant$^{-1}$ | 100 seed weight (g) | Days to maturity | Seed yield plant$^{-1}$ (g) |
|---|---|---|---|---|---|---|---|---|
| 100 Seed weight (g) | $C_1$ | | | | | **1.0000** | 0.0558 | 0.1905 |
| | $C_2$ | | | | | **1.0000** | 0.0589 | 0.2775* |
| | $C_3$ | | | | | **1.0000** | 0.0138 | 0.1972* |
| | $C_4$ | | | | | **1.0000** | 0.0821 | 0.3274** |
| Days to maturity | $C_1$ | | | | | | **1.0000** | 0.0006 |
| | $C_2$ | | | | | | **1.0000** | 0.0580 |
| | $C_3$ | | | | | | **1.0000** | 0.1894* |
| | $C_4$ | | | | | | **1.0000** | -0.0151 |
| Seed yield plant$^{-1}$ (g) | $C_1$ | | | | | | | **1.0000** |
| | $C_2$ | | | | | | | **1.0000** |
| | $C_3$ | | | | | | | **1.0000** |
| | $C_4$ | | | | | | | **1.0000** |

*Significant @ P = 0.05 **Significant @ P = 0.01

Where, $C_1$ : A-1 × JG 315

$C_2$ : A-1 × HC 5

$C_3$ : JG 11 × JG 24

$C_4$ : JAKI 9218 × HC 5

### 4.9 Path coefficient analysis

Path coefficient analysis was carried out at phenotypic level for six traits which have shown significant correlation with pod yield plant$^{-1}$ in $F_2$ population of four crosses. The results are presented in Table 16.

#### 4.9.1 Direct effects of traits related to yield components on seed yield plant$^{-1}$

Among the traits studied, number of pods plant$^{-1}$ exhibited highest positive direct effect of 0.8951 in cross A-1 × JG 315, 0.6352 in cross A-1 × HC 5 followed by 100 seed weight in the two crosses, JAKI 9218 × HC 5 (0.3980) and A-1 × HC 5 (0.3702) on seed yield plant$^{-1}$. Traits like number of primary branches in cross JG 11 × JG 24 (0.3499), plant height in cross JG 11 × JG 24 (0.3114), days to 50 *per cent* flowering in three crosses *viz.,* A-1 × JG 315 (-0.0229), A-1 × HC 5 (-0.0009) and JAKI 9218 × HC 5 (-0.0251) showed negligible negative direct effect on seed yield plant$^{-1}$.

#### 4.9.2 Indirect effect of yield contributing characters on seed yield plant$^{-1}$

The traits *viz*., number of pods plant$^{-1}$, number of primary branches had highest magnitude of indirect effect on seed yield plant$^{-1}$ through plant height and also number of primary branches. Among the four crosses, number of pods plant$^{-1}$ exhibited highest positive indirect effect on seed yield plant$^{-1}$ in the cross A-1 × JG 315 (0.4562) and A-1 × HC 5 (0.3345) through number of primary branches. Number of primary branches exhibited highest positive indirect effect on seed yield plant$^{-1}$ in the cross JG 11 × JG 24 (0.1320, 0.1105) through number of pods plant$^{-1}$ and plant height.

Plant height have highest magnitude of indirect effect on seed yield plant$^{-1}$ in the cross JG 11 × JG 24 (0.0983) through number of primary branches. For days to 50 *per cent* flowering the cross JG 11 × JG 24 (-0.0005) exhibited highest negative indirect effect on seed yield plant$^{-1}$ through number of pods plant$^{-1}$. Whereas, 100 seed weight showed highest positive indirect effect on seed yield plant$^{-1}$ in the cross JAKI 9218 × HC 5 (0.0327) through days to maturity.

**Table 16. Estimates of direct and indirect effects of different characters on seed yield plant$^{-1}$ in $F_2$ population of the four crosses**

| Traits | Crosses | Days to 50% flowering | Plant height (cm) | Number of primary branches | Number of pods plant$^{-1}$ | 100 seed weight (g) | Days to maturity | Seed yield plant$^{-1}$ (g) |
|---|---|---|---|---|---|---|---|---|
| Days to 50 % flowering | $C_1$ | **-0.0229** | 0.0010 | 0.0022 | 0.0013 | -0.0021 | 0.0008 | -0.0444 |
| | $C_2$ | **-0.0009** | 0.0001 | 0.0001 | 0.0025 | 0.0004 | 0.0002 | -0.0246 |
| | $C_3$ | **0.0192** | 0.0028 | -0.0011 | -0.0005 | 0.0029 | 0.0003 | 0.0576 |
| | $C_4$ | **0.1090** | 0.0117 | 0.0028 | 0.0087 | -0.0019 | -0.0058 | 0.0938 |
| Plant height (cm) | $C_1$ | -0.0005 | **0.0114** | 0.0023 | 0.0049 | 0.0003 | 0.0002 | 0.4041 |
| | $C_2$ | -0.0045 | **0.0378** | 0.0159 | 0.0174 | -0.0045 | 0.0047 | 0.3021 |
| | $C_3$ | 0.0453 | **0.3114** | 0.0983 | 0.0888 | 0.0652 | 0.0121 | 0.5464 |
| | $C_4$ | 0.0276 | **0.2688** | 0.0360 | 0.0600 | -0.0284 | -0.0181 | 0.2904 |
| Number of primary branches | $C_1$ | -0.0003 | 0.0007 | **0.0033** | 0.0017 | -0.0003 | 0.0004 | 0.4329 |
| | $C_2$ | -0.0038 | 0.0149 | **0.0354** | 0.0186 | -0.0030 | 0.0030 | 0.3551 |
| | $C_3$ | -0.0204 | 0.1105 | **0.3499** | 0.1320 | -0.0071 | 0.0269 | 0.5709 |
| | $C_4$ | -0.0302 | 0.0227 | **0.1697** | 0.0571 | -0.0258 | -0.0138 | 0.2091 |

**(Contd……)**

| | Crosses | Days to 50% flowering | Plant height (cm) | Number of primary branches | Number of pods plant$^{-1}$ | 100 Seed weight (g) | Days to maturity | Seed yield plant$^{-1}$ (g) |
|---|---|---|---|---|---|---|---|---|
| Number of pods plant$^{-1}$ | $C_1$ | -0.0517 | 0.3834 | 0.4562 | **0.8951** | -0.1373 | 0.0238 | 0.8522 |
| | $C_2$ | -0.0028 | 0.2917 | 0.3345 | **0.6352** | -0.0858 | 0.0180 | 0.6214 |
| | $C_3$ | -0.0082 | 0.0901 | 0.1193 | **0.3162** | 0.0018 | 0.0537 | 0.5533 |
| | $C_4$ | -0.0052 | 0.0411 | 0.0620 | **0.1842** | -0.0188 | -0.0242 | 0.2599 |
| 100 Seed weight (g) | $C_1$ | 0.0307 | 0.0077 | -0.0303 | -0.0505 | **0.3295** | 0.0184 | 0.1905 |
| | $C_2$ | -0.0102 | -0.0437 | -0.0317 | -0.0500 | **0.3702** | 0.0218 | 0.2775 |
| | $C_3$ | 0.0200 | 0.0279 | -0.0027 | 0.0008 | **0.1332** | 0.0018 | 0.1972 |
| | $C_4$ | -0.0244 | -0.0420 | -0.0605 | -0.0407 | **0.3980** | 0.0327 | 0.3274 |
| Days to maturity | $C_1$ | 0.0003 | -0.0001 | -0.0009 | -0.0002 | 0.0004 | **-0.0074** | -0.0006 |
| | $C_2$ | -0.0023 | 0.0013 | 0.0009 | 0.0003 | 0.0006 | **0.0104** | 0.058 |
| | $C_3$ | 0.0017 | 0.0037 | 0.0073 | 0.016 | 0.0013 | **0.0945** | 0.1894 |
| | $C_4$ | 0.0006 | -0.0007 | -0.0009 | -0.0014 | 0.0009 | **0.0108** | -0.0151 |

*Significant @ P = 0.05 **Significant @ P = 0.01

Bold face diagonal values indicate direct effects.

Residual effects $C_1$ : A-1 × JG 315 = **0.40**

$C_2$ : A-1 × HC 5 = **0.11**

$C_3$ : JG 11 × JG 24 = **0.21**

$C_4$ : JAKI 9218 × HC 5 = **0.13**

# V DISCUSSION

Seed yield is of primary importance and the most complex trait as it is dependent upon the interaction of growth, environment and genetic makeup of the plant. Yield is the ultimate goal of a breeding program. Seed yield being most important trait, is governed by many physiological changes within the plant and influenced by many environmental factors. So, the breeder needs some index traits to select elite genotype for higher yield. Information on correlation, path-coefficients and selection index analyses is of much use to plant breeders for selection and breeding genotypes with increased yield potential.

The exploitation of heterosis is one of the breeding strategies to enhance the productivity. In practical heterosis breeding, it is imperative to select the cross combinations with high degree of specific combining ability (sca) as well as parents with high general combining ability (gca). The magnitude of heterosis particularly for yield is of paramount importance and if the heterosis is of high magnitude, it can help to achieve high productivity and there by high yield levels.

With this back ground, the present investigation was carried out in chickpea and results are discussed under the following heads.

5.1 Mean performance of parents and crosses

5.2 Analysis of variance

5.3 Combining ability effects and gene action

5.3.1 General combining ability effects

5.3.2 Overall general combining ability status of parents

5.3.3 Specific combining ability effects

5.3.4 Proportional contribution of lines, testers and line × tester interaction

5.4 Variance due to general and specific combining ability

5.5 Heterosis

5.5.1 Mid parent and standard heterosis

5.5.2 Overall Specific combining ability and heterotic status of crosses

5.6 Genetic variability parameters

5.7 Correlation among different characters for yield and yield attributing traits

5.8 Path co-efficient for yield and yield attributing traits

5.9 Future line of work

### 5.1. Mean performance of parents and crosses

Among the lines, JAKI 9218 exhibited highest *per se* performance with respect to days to 50 *per cent* flowering, Plant height and days to maturity followed by A-1 for the trait number of primary branches, number of pods per plant and seed yield per plant and for 100 seed weight.

Among the testers JG 24 manifested high *per se* performance with respect to plant height and 100 seed weight and seed yield per plant. However, for traits viz., days to 50 *per cent* flowering, number of primary branches, HC 5 exhibited highest *per se* performance.

In general, no single cross showed higher mean performance for all the traits. Nevertheless, the cross, JG 11 × JG 24, exhibited higher *per se* performance for seed yield per plant and 100 seed. The cross combination JG 11 × HC 5 manifested higher mean value for number of pods per plant. The higher average plant height and also number of primary branches was noticed in the cross A-1 × HC 5.

### 5.2 Analysis of variance

Highly significant differences among the parents (lines + testers) as evident from ANOVA (Table 3) for four characters viz., days to 50 *per cent* flowering, plant height, 100 seed weight and days to maturity, justify the selection of parents for the study. The crosses also differed significantly for most of the yield attributing traits either due to one of the parent or both the parents. Significant differences among the crosses could be due to differences among both the parents. Significant variance due to lines × testers suggested involvement of non allelic gene action in the inheritance of 100 seed weight. Significance of variance due to line × tester interaction in chickpea for yield and yield attributing traits was reported by Bahl and Kumar (1989).

### 5.3 Combining ability effects and gene action

#### 5.3.1 General combining ability effects

The estimates of gca effects of parents helps in isolating useful parental lines which could be further exploited in development of improved varieties by concentrating on desirable genes with additive effect. The magnitude and direction of gca effects varied with lines and testers as well as with the traits, indicating differential ability to transmit additive genes to the progeny. No single line or testers was a good general combiner for all traits. The present study helped to identify lines and testers with high gca effect.

The estimates of gca effects of lines and testers indicate that, no single line or testers was a good general combiner for all traits. Nevertheless, JAKI 9218 and JG 11, among the lines was a good general combiner and hence appeared to transmit additive genes for the traits, viz., days to 50 *per cent* flowering, plant height, seed yield per plant, 100 seed weight and days to maturity.

Among the testers, JG 24 exhibited significant gca effects in the desirable direction for days to 50 *per cent* flowering, seed yield per plant, 100 seed weight and days to maturity. JG 315 was next best tester with significant gca effect for all the characters except days to 50 *per cent* flowering, plant height, and number of pods per plant. It would be rewarding to involve these good general combining lines and testers in crossing programs to generate useful variability. The selection from such variable population will be effective in identifying genotypes with desirable combination of selected productivity traits.

### 5.3.2 Over all general combing ability status of parents

As various quantitative traits are either positively or negatively correlated, it is usual to find for a particular character, gca in the desired direction for some characters and in the undesirable directions for others. This is true in the present investigation also as is discussed in the previous section on gca effects. That no single line or a tester was a good general combiner for all the characters studied. The problem of ascertaining the status of parents with respect to its gca over a number of traits assumes importance. In this contest, the lines and testers were classified as overall high (H) and overall low (L) general combiners based on method proposed by Arunachalam and Bandyopadhyay (1979).

The estimates of overall gca status of parents (Table 8) indicated that, the tester JG 24 was good general combiner with high (H) overall gca status. Among lines A-1 and JG 11 were good general combiner as evident from their high (H) overall gca status.with high (H) overall gca status.The results implies that two lines and one tester studied were high overall good general combiner suggesting their average ability to transmit additive genes in the desirable direction to their progenies.

### 5.3.3 Specific combining ability effects

The estimates of specific combining ability (sca) effects (Table 9) of nine crosses for different attributes are discussed character-wise;

#### 5.3.3.1 Days to 50 *per cent* flowering

For days to 50 *per cent* flowering, three hybrids viz., A-1 × HC 5, JAKI 9218 × HC 5, and JAKI × JG 315 had significant sca effects, which belonged to different classes of parental combinations based on overall gca effects. All the three crosses had either H × L, or L × L parental combinations indicating the influence of both additive and non additive gene actions in the inheritance of this trait. These results are similar to those reported by Bahl and Kumar (1989) and Venkatraman *et al*. (2007).

#### 5.3.3.2 plant height (cm)

Two hybrids out of nine manifested significant sca effects viz., A-1 × JG 24, JG 11 × JG 24, recorded high sca effects and these crosses belong to H × H parental combination indicating influence of additive gene actions in the inheritance of this trait. Similar reports were also made by Chauhan *et al*. (2013).

### 5.3.3.3 Number of primary branches

The cross JAKI 9218 × HC 5 exhibited significant sca effect among all nine crosses and this cross belong to L × L parental combination indicating influence of both additive and non additive gene actions in the inheritance of this trait and also both the parents have complementary gene interactions which resulted in high heterosis. These findings are in agreement with those of Bahl and Kumar (1989), Bhardwaj *et al*. (2010), Gadekar and Dodiya (2013) and Venkatraman *et al*. (2007).

### 5.3.3.4 Number of pods plant$^{-1}$

Significant sca effect was exhibited by JAKI 9218 × JG -24. This superior cross belongs to L × H category depicting the presence of both additive and non additive gene action which indicates that additive genetic action present in the good combiner and complementary epistatic effects present in the cross and in the same direction that resulted in maximum desirable plant attributes. Similar reports were also made by Bahl and Kumar (1989), Bhardwaj *et al*. (2010).

### 5.3.3.5 Seed yield plant$^{-1}$

Positive significant sca effects were exhibited by four crosses which were A-1× JG 315, JAKI 9218 × JG 315, JG 11 × HC 5, JG 11 × JG 24. These superior crosses involved parental combinations H × L, L × L, H × H gca status indicating influence of both additive and non additive gene action in the genetic control of this trait. These findings are in agreement with those of Chauhan *et al*. (2013), Gadekar and Dodiya (2013) and Jayalakshmi *et al*. (2011).

### 5.3.3.6 Hundred seed weight

The crosses JAKI 9218 × JG 315 and JG 11 × JG 315 were superior combiners for this trait and these hybrids belongs to either L × L or H × L parental combinations indicating the presence of additive as well as non additive gene actions. Similar observations were also made by Chauhan *et al*. (2013).

### 5.3.3.7 Days to maturity

All the crosses exhibited significant positive or negative sca effects of which A-1× JG 315, JAKI 9218 × JG 315, JG 11 × HC 5, JG 11 × JG 24 were exhibited significant negative sca effect in desirable direction which belongs to either H × L, L × L, or H × H parental combinations indicating presence of additive as well as non additive gene actions in the inheritance of days to maturity. Studies of Bahl and Kumar (1989) and Gadekar and Dodiya (2013) support the present findings.

**Table 17. Top ranking crosses with desirable sca effects for different characters**

| Characters | Cross | Mean | sca effects | Type of combination |
|---|---|---|---|---|
| Days to 50% flowering | JAKI × HC -5 | 37 | 0.83* | L × L |
| | A-1 × HC -5 | 34.5 | 0.83* | H × L |
| | JAKI × JG-315 | 36.5 | -0.83* | L × L |
| | | | | |
| Plant height | JG-11 × JG -24 | 41.5 | 0.56** | H × H |
| | A-1 × JG -24 | 39.6 | -1.05* | H × H |
| | | | | |
| Number of primary branches | JAKI × HC -5 | 7.9 | -1.03** | L × L |
| | | | | |
| Number of pods plant $^{-1}$ | JAKI ×JG -24 | 54.93 | -3.95* | L × H |
| | | | | |
| Seed yield/ plant (g) | A-1× JG- 315 | 17.56 | 4.36** | H × L |
| | JG-11 × HC -5 | 23.82 | 2.72** | H × L |
| | JG-11 × JG -24 | 24.36 | 2.17** | H × H |
| | | | | |
| 100 Seed weight (g) | JAKI × JG-315 | 24 | 2.12* | L × L |
| | JG-11 × JG - 315 | 19.55 | -2.19* | H × L |
| | | | | |
| Days to maturity | A-1× JG- 315 | 92 | -1.55** | H × L |
| | JAKI × JG-315 | 96 | -1.55** | L × L |
| | JG-11 × HC -5 | 96 | -1.55** | H × L |
| | JG-11 × JG -24 | 96 | -1.55** | H × H |

From the above discussion it is evident that, no single cross was a superior specific combination for all the characters under study. However, the cross, JAKI 9218 × JG 315 was the specific cross combination for four important characters *viz*., Days to 50 *per cent* flowering, Seed yield per plant, 100 Seed weight, and days to maturity which belongs to L × L type of cross. Evidently, low X low combination was not a barrier for recovering heterotic crosses. Such heterotic hybrids arising from poor combining parents in chickpea are not unusual (Bahl and Kumar, 1989). The next best cross was JAKI 9218 × HC -5 and JG-11 × JG -24 which had significant sca effect for three characters. Best crosses for majority of the characters involved at least one general combining parent, therefore it is desirable to select one parent with high general combining ability and other with low general combining ability for obtaining crosses with high sca effects.

Parents with low x low or high x low gca effects yields best specific combiners for grain yield and its components (Bhardwaj *et al*., 2010) and also the parents with high and low or both with low gca effects resulted in best specific cross combinations. Thus, high sca effects or heterosis for any cross does not necessarily depend on the gca effects of the parents involved. The superiority of that cross may be due to complementary type of gene interaction which can be exploited in the subsequent generations.

### 5.3.4 Proportional contribution of parents and their interaction

From the table 10, it can be noticed that, the contribution of lines to total variation was higher for the characters like plant height and days to maturity followed by testers and line × tester interaction. While, the contribution of testers was more towards total variance for the traits like days to 50 *per cent* flowering, number of primary branches, 100 seed weight and seed yield plant$^{-1}$.

However, the variation in the performance of hybrids was by and large due to the effect of tester followed by moderate contribution from lines and lower contribution from line × tester interaction.

## 5.4 Variance due to general and specific combining ability for yield and yield attributing characters

The ratio of GCA variance to SCA variance reflects the nature of gene action. For all the traits except plant height and number of primary branches, the result of the present study indicated the predominance of SCA variance which implied non additive gene action (dominance, additive × dominance, or dominance × dominance) operating for the expression of the characters.

In the present study magnitude of SCA was greater than magnitude of GCA and was highest for number of pods per plant followed by seed yield per plant, days to maturity, 100 seed weight and days to 50 *per cent* flowering (Table -9), indicating more of non additive gene action for yield and yield attributing characters. The results of the present investigation was in agreement with Bhatt and Singh (1980), Bahl and Kumar (1988), Gadekar and Dodiya (2013), chauhan *et al*. (2013). On the contrary the magnitude of GCA was greater than SCA for plant height and number of primary branches revealing that additive gene action was more involved than non additive gene action.

### 5.5 Heterosis for yield and yield attributing traits

#### 5.5.1 Mid parent and standard heterosis

Significant average heterosis for all the attributes suggested the possibility of obtaining elite lines in the Segregating generations for the genetic improvement of chickpea. There is a possibility to sort out the recombinants possessing most of the desirable yield and its contributing traits. For a character, when significant heterosis over mid parent is observed in majority of the crosses, it indicates non additive gene action for that character. Assuming that epistasis is absent, the cause of heterosis can be attributed to dominance gene action. Heterosis for different characters, are presented below, based on this assumption.

The standard heterosis over check JG 11 and heterosis over midparent for yield and yield attributing characters are presented in the Table 12 and are discussed below character wise;

##### 5.5.1.1 Days to 50 *per cent* flowering

Out of nine hybrids, five hybrids showed significant heterosis for days 50 *per cent* flowering, over mid parent and two hybrids exhibited significant positive heterosis over standard check JG 11, indicating that dominance type of gene action is prevalent for this character. The range of heterosis over mid parent was -16.38 to 4.23. The hybrid JAKI 9218 × HC 5 exhibited highest mid parent negative heterosis (-16.38 *per cent*) in desirable direction. Similar observations were made by Bahl and Kumar (1989), Gadekar and N.S. Dodiya (2013), and Bhardwaj *et al.* (2010) depicted desirable significant negative mid parent heterosis for both the maturity related traits indicating that the genes with negative effects were dominant.

##### 5.5.1.2 plant height

Out of nine hybrids, three hybrids expressed significant negative heterosis for plant height. The cross combination JAKI 9218 × JG 315 expressed higher negative heterosis over standard check JG 11. None of the crosses were found significant positive relative heterosis for plant height indicated that none of the genes with positive dominant effects for this trait. The result obtained in present investigation was contradictory with those of Gadekar and Dodiya (2013).

Six hybrids showed significant negative mid parent heterosis for plant height. Here significant heterosis over mid parent is observed in majority of the crosses, indicating presence of non additive gene action for plant height. These results are in agreement with Bhardwaj *et al.* (2010).

#### 5.5.1.3 Number of primary branches

Five crosses out of nine, manifested significant positive heterosis over standard check JG 11 for number of primary branches. The highest significant heterosis was found to be expressed by A-1 × HC 5 for number of primary branches followed by JAKI 9218 × JG 24. These results are in conformity with Chauhan *et al.* (2013) and Deshmukh *et al.* (1982).

Four hybrids showed significant positive mid parent heterosis for number of primary branches. The highest significant mid parent heterosis was found to be expressed by JG 11 × JG 24 for number of primary branches followed by JAKI 9218 × JG 24. The result obtained in present investigation was contradictory with those of Mandal and Bahl (1983), Ahmed Bakhsh *et al.* (2007) and Reddy Yamini *et al.* (2015).

#### 5.5.1.4 Number of pods plant$^{-1}$

For number of pods plant$^{-1}$, only three crosses manifested significant positive heterosis over commercial check JG 11. The cross JG 11 × HC 5 expressed the higher heterosis followed by A-1 × JG 24. The result obtained in present investigation was contradictory with those of Gadekar and Dodiya (2013) and Chauhan *et al.* (2013).

While only one cross manifested significant positive mid parent heterosis for number of pods per plant. The results suggest limited variability among the parents and their ability to produce heterotic hybrids. This calls for involvement of diverse parents to develop heterotic hybrids. These results are in agreement with Mandal and Bahl (1983), Ahmed Bakhsh *et al.* (2007), and Reddy Yamini *et al.* (2015).

#### 5.5.1.5 Seed yield plant$^{-1}$

For seed yield plant$^{-1}$, six crosses manifested significant positive heterosis over commercial check JG 11. The cross JG 11 × JG 24 expressed the higher heterosis followed by JG 11 × HC 5. The result obtained in the present investigation was contradictory with those of Gadekar and Dodiya (2013), Deshmukh and Bhapkar (1982) and Chauhan *et al.* (2013).

Four hybrids showed significant positive mid parent heterosis for seed yield per plant. The highest significant mid parent heterosis was found to be expressed by JG 11 × HC 5 for seed yield plant$^{-1}$ followed by JG 11 × JG 24. These results are in agreement with Bahl and Kumar (1988), Mandal and Bahl (1983) and Ahmed Bakhsh *et al.* (2007).

#### 5.5.1.6 100 seed weight

Only two crosses, JAKI 9218 × HC 5, JAKI 9218 × JG 315 exhibited significant positive mid parent heterosis for 100 seed weight. The result obtained in present investigation was contradictory with those of Bhardwaj *et al.* (2010) and Jayalakshmi *et al.* (2011). Five crosses manifested significant negative heterosis over commercial check JG 11. These results are in agreement with Bahl and Kumar (1988) who reported negative non significant standard heterosis.

### 5.5.1.7 Days to maturity

For days to maturity, all the nine crosses manifested significant negative mid parent heterosis. The cross A-1 × JG 24 expressed the higher mid parent heterosis followed by A-1 × HC 5. The result obtained in the present investigation was contradictory with those of **S**antosh Bhatnagar *et al*. (2006) and Bhardwaj *et al.* (2010). Also, all the nine crosses showed significant positive standard heterosis for days to maturity. These results are in conformity with Gadekar and Dodiya (2013) and Chauhan *et al*. (2013).

In summarizing, significant standard heterosis was noticed in all the characters namely, days to 50 *per cent* flowering, plant height, number of primary branches, number of pods per plant, seed yield per plant, 100 seed weight, and days to maturity. Most of the hybrids showed significant heterosis over standard check, which indicates selected productivity traits in case of JG 11 was lower than majority of experimental hybrids.

The crosses showing non additive type of gene action as revealed by their substantial heterosis over their mid parents also are likely to throughout desirable segregants, but those can be stabilized only if additive × additive type of epistasis is the major component.

### 5.5.2 Overall sca and heterotic status of crosses:

As in the case of gca and sca, the magnitude and direction of heterosis varied from character to character. Therefore, it was difficult to decide superiority of cross over the check for the selected productivity traits or for at least a few important traits. Hence, to decide whether a cross could be considered as overall sca and heterotic cross or not, across the characters, a method proposed by Arunachalam and Bandyopadhyay, (1979) modified by Mohan Rao, (2001) was employed.

Based on the overall gca effects the crosses were classified into HH (both the parents in the hybrid with high overall gca status), HL (one parent with high and the other with low overall gca status) and LL (both the parents in the hybrid with low gca status).

Based on this method it was found that five of the nine crosses had high over all specific combining ability status across the traits studied and remaining four crosses belongs to overall low specific combination. Five hybrids manifested a high (H) overall heterotic status and the remaining four crosses expresses low (L) overall heterotic status across the traits.

It is worth mentioning here that whenever a female parent with high gca status was involved, it produced crosses with high overall sca and heterotic status for the yield and yield attributing traits. This suggested the ability of female parent in transmitting additive alleles with increasing effect to their progeny, suggesting the emphasis to be laid on the gca effects for the selection of parents for hybridization. The tester JG 24 was found to produce high frequency of heterotic crosses followed by HC 5.

### 5.6 Genetic variability studies

Variability refers to the presence of genotypic and phenotypic differences among the individuals of plant population. Variability may be due to genetic constitution of the individuals of a population or due to environment in which they are grown. Selection is effective only when there is genetic variability among the individuals in a population. Hence, insight into the magnitude of genetic variability present in a population is of paramount importance to plant breeders. The total variability in the material cannot be inferred only by mean and range values. Hence, actual variance has been estimated for characters to know the existing variability. The phenotypic variance indicates the amount of variation which is due to differences in phenotypic values.

Higher estimates of PCV were observed for number of primary branches, number of pods per plant and seed yield per plant in all the four crosses *viz*., JAKI 9218 × HC -5, A-1 × JG 315, A-1 × HC 5 and JG 11 × JG 24, whereas, higher estimates of PCV were observed for 100 seed weight in two crosses viz., A-1 × JG 315 and A-1 × HC 5 of $F_2$ population. The higher estimates of PCV for the above mentioned traits suggests the presence of higher magnitude of variation for these traits. Thus individual plant selection can be practiced for these characters. Similar findings were reported by Parashi and lad (2013) for number of pods per plant and seed yield per plant, Kanouni *et al.* (2012), Rajkumar Kuldeep *et al.* (2014) found similar result for all the above traits.

PCV estimates were moderate for plant height in all the four crosses *viz*., JAKI 9218 × HC -5, A-1 × JG 315, A-1 × HC 5 and JG 11 × JG 24 and moderate for 100 seed weight in the crosses JAKI 9218 × HC 5 and JG 11 × JG 24. These estimates of PCV for the above mentioned traits indicate the presence of variability for these traits. Thus individual plant selection can be practiced for improvement of these traits. These results are in conformity with the reports of Anjani Kumar Singh *et al.* (2014) and Kamla Desai *et al*. (2015).

But lower estimates of PCV were recorded for days to 50 per cent flowering and days to maturity in all the four crosses. This indicates lower magnitude of variation for these traits. Similar findings were reported by Parashi and lad (2013) for days to maturity, Kanouni *et al*. (2012) for both the traits.

### 5.7 Association among the different characters including yield in $F_2$ population of four crosses

Correlation analysis provides useful information for basis of selection for trait like yield. Seed yield is the most economic as well as very complex character in nature because it is governed by polygene and greatly influenced by environmental factors (Kumar Abhishek *et al*. 2012). Therefore, direct selection for yield may not be effective in a polygenic character. An improvement in yield can be brought about by effecting indirect selection for yield contributing characters, whose heritability is high and show a strong association with yield. The degree of association between two characters is measured by correlation or character association. Correlation studies between yield and its component traits would help plant breeders to enhance crop growth and yield of crop.

In the present study, phenotypic correlation between seed yield per plant with component characters were studied in $F_2$ population of in four crosses *viz.,* A-1 × JG 315, A-1 × HC 5, JG 11 × JG 24, and JAKI 9218 × HC 5.

### 5.7.1 Seed yield with other characters

Phenotypic correlation coefficient revealed that seed yield per plant had significant positive correlation with plant height and number of pods per plant in all four crosses studied A-1 × JG 315, A-1 × HC 5, JG 11 × JG 24, JAKI 9218 × HC 5 and for number of primary branches in crosses A-1 × JG 315, A-1 × HC 5, JG 11 × JG 24. seed yield per plant had significant positive correlation with 100 seed weight in crosses A-1 × HC 5 and JG 11 × JG 24, this indicates that any positive increase in these traits will accelerate the boost in seed yield per plant. These results are in accordance with the reports of Kumar Abhishek *et al.* (2012), Nihal Kayan and Sait Adak (2012), Meena *et al*. (2006) and Anita Babbar et al. (2012).

### 5.7.2 Correlation among other characters

At the phenotypic levels, days to 50 *per cent* flowering was found negative correlation with plant height and number of primary branches in three crosses *viz.,* A-1 × JG 315, A-1 × HC 5 and JAKI 9218 × HC 5. For number of pods per plant, days to 50 *per cent* flowering showed negative correlation for all the four crosses and it was found negatively correlated with 100 seed weight for two crosses A-1 × HC 5 and JAKI 9218 × HC 5, Whereas for days to maturity, except one cross A-1 × JG 315 all other crosses showed positive correlation. These findings are in conformity with that Qurban Ali *et al*. (2012), Derya Ozveren Yucel *et al*. (2006) and Lal Hussain Akhtar *et al*. (2011).

In the present study, plant height exhibited highly positive and significant association with number of primary branches and number of pods per plant for all the crosses except JAKI 9218 × HC 5 in which positive association was noticed for number of primary branches. Plant height was found to be negatively correlation with 100 seed weight for the crosses A-1 × HC 5 and JAKI 9218 × HC 5, whereas, the cross JG 11 × JG 24 exhibited highly positive and significant association for plant height. These results are supported by the findings of Sachin Parhe *et al*. (2014), Mustafa Guler *et al*. (2001), Rajkumar Kuldeep *et al*. (2014) and Uday Chand Jha *et al*. (2012).

Number of primary branches exhibited positive and significant association with number of pods per plant for all the crosses, and it was found negatively correlation with 100 seed weight for all the crosses. Whereas, number of primary branches showed positive association with days to maturity for all the crosses, except JAKI

9218 × HC 5. These findings are in conformity with Neelu Kumari *et al.* (2013), Abhishek Kumar *et al*. (2012) and Bashir Ahmed Malik *et al*. (1988).

In the present study, number of pods per plant showed negative and significant association with 100 seed weight for two crosses A-1 × JG 315 and A-1 × HC 5 and there was a positive and significant association with days to maturity in cross JG 11 × JG 24. Whereas, number of pods per plant exhibited negative association with days to maturity in the cross JAKI 9218 × HC 5. These results are supported by the findings of Lal Hussain Akhtar *et al*. (2011), Dar *et al*. (2012) and Kanaka Durga *et al*. (2007).

In the present study , 100 seed weight displayed positive association with days to maturity for all the crosses except A-1 × JG 315. These results are in conformity with that of Jeena *et al*. (2005), Meena *et al.* (2006) and Uday Chand Jha *et al.* (2012).

**5.8 Path coefficient analysis in $F_2$ population of four crosses**

Path analysis concept was developed by Sewell Wright in 1921. It was carried out to split the phenotypic correlation coefficient into direct and indirect effects. It measures the direct and indirect contribution of various independent variables on a dependent variable i.e. it reveals whether the independent variable is directly contributing to the dependent variable or it is contributing indirectly via other component characters on which selection can be practiced for improvement of the yield.

Number of pods per plant exhibited maximum direct effect on seed yield per plant in two crosses *viz*., A-1 × JG 315 and A-1 × HC 5. Whereas, number of primary branches exhibited maximum direct effect on seed yield per plant in the cross JG 11 × JG 24 while in JAKI 9218 × HC 5, 100 seed weight exhibited maximum direct effect on seed yield per plant. Thus maximum direct effect of number of pods per plant, number of primary branches and 100 seed weight indicates, greater contribution of these traits towards seed yield. These results are in agreement with the reports of Anita Babbar *et al*. (2012), Rajkumar Kuldeep *et al*. (2014), and Samad *et al*. (2014).

Maximum positive indirect effect was shown by number of pods per plant through plant height and number of primary branches followed by plant height through number of pods per plant in all the four crosses. The present result are supported by Kumar Abhishek *et al*. (2012), Sachin Parhe *et al*. (2014), Dar *et al* (2012) and Neelu Kumari *et al*. (2013).

The present study indicated a maximum direct effect of number of pods per plant, number of primary branches and 100 seed weight in the respective crosses. The traits, number of pods per plant and plant height manifested maximum indirect effect towards seed yield per plant. Hence, main emphasis should be given on these traits *viz*., number of pods per plant, number of primary branches, and 100 seed weight and plant height while selecting for high seed yield.

### 5.9 Future line of work

1. The line JG 11 and tester JG 24 with good gca effects were identified and can be used as parents for future hybridization programme.

2. The crosses namely, A-1 × JG 315, JG 11 × HC 5 and JG 11 × JG 24 with high sca effects can be forwarded to next generation to isolate transgressive segregants.

# VI SUMMARY

An investigation was carried out at the experimental plots of Zonal Agricultural Research Station (ZARS), Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences, Bengaluru during Rabi-Summer 2014-15 to evaluate 9 new hybrids developed from Line X Tester mating design along with their 6 parents (3 lines and 3 testers) for generating information on combining ability of parents and hybrids, gene action, and heterosis in respect of seed yield and its attributing traits. During Rabi 2015, $F_1$ crosses were forwarded to $F_2$ generation and variability for seed yield and its component traits and interrelationship among quantitative traits was assessed.

The material for the study comprised of three lines A-1, JG-11, and JAKI-9218 and three testers JG-315, HC-5, JG-24, Which were crossed in a line x tester mating design to synthesize nine hybrids. Based on heterosis**,** nine $F_1$ crosses were forwarded to $F_2$ generation.

The salient features of the investigation are summarized here under.

- Highly significant differences in mean sum of squares was observed among the parents (lines + testers) and crosses for some of the yield and its attributing traits.

- Among the lines JAKI 9218 exhibited highest *per se* performance with respect to days to 50 *per cent* flowering, Plant height and days to maturity followed by A-1 for the traits, number of primary branches, number of pods per plant and seed yield per plant and for 100 seed weight.

- Among the testers JG 24 manifested high *per se* performance with respect to plant height and 100 seed weight and seed yield per plant. However, for traits *viz*., days to 50 per cent flowering, number of primary branches, HC 5 manifested highest *per se* performance.

- Among the lines JAKI 9218 and JG 11 exhibited additive and increasing genetic effects with respect to days to 50 *per cent* flowering, plant height, seed yield per plant, 100 seed weight and days to maturity.

- Among the testers, JG 24 manifested significant gca effects for days to 50 per cent flowering, seed yield per plant, 100 seed weight and days to maturity.

- Among the lines, A-1 and JG 11 and among testers JG 24 were found to be high over all general combiners.

- The cross, JAKI 9218 × JG 315 exhibited significant higher sca effects in desirable direction for as many as four traits namely, Days to 50 per cent flowering, Seed yield per plant, 100 Seed weight and days to maturity.

- Most of the best performing crosses for majority of the characters involved at least one high general combining parent.

- The variation in the performance of hybrids was large due to the effect of tester followed by moderate contribution from lines and lower contribution from line × tester. Importance of non additive gene action reflected in the predominance of contributions of line × tester interaction for the traits *viz.*, number of pods per plant.

- Variance due to sca effects was more than that due to gca effects suggesting the involvement of non additive gene action in the inheritance of number of pods per plant followed by seed yield per plant, days to maturity, 100 seed weight and days to 50 per cent flowering.

- Significant standard heterosis was noticed in all the characters namely days to 50 percent flowering, plant height, number of primary branches, number of pods per plant, seed yield per plant, 100 seed weight, and days to maturity. Most of the hybrids showed significant heterosis over standard check, which indicates selected productivity traits in case of JG 11 was lower than majority of experimental hybrids.

- Given a cross with high overall gca status, the probability of it to be an H × L/L × H combination was higher than the probability of finding it to be an L × L or H × H combinations. Similarly, given a heterotic cross, the probability of finding it to be an H × L combinations was higher than the probability of finding it to be either H × H, L × H or L × L combinations.

- Hence, when a breeder has to attempt successful hybridization economically in terms of time, cost and number of crosses it is worth while to start with H × L type of crosses followed by H × H for realizing hybrids with high heterosis.

- Phenotypic correlation coefficient depicted seed yield per plant had significant positive correlation with plant height and number of pods per plant in crosses A-1 × JG 315, A-1 × HC 5, JG 11 × JG 24, JAKI 9218 × HC 5 and for number of primary branches in crosses A-1 × JG 315, A-1 × HC 5, JG 11 × JG 24. seed yield per plant had significant positive correlation with 100 seed weight in crosses A-1 × HC 5 and JG 11 × JG 24.

- Path coefficient analysis for seed yield per plant revealed maximum direct effect of number of pods per plant, number of primary branches, and 100 seed weight in the respected crosses. The traits number of pods per plant and plant height manifested maximum indirect effect towards seed yield per plant. Hence main emphasis should be given on these traits viz., number of pods per plant, number of primary branches, and 100 seed weight and plant height while selecting for high seed yield.

- Indirect selection of genotype based on 100 seed weight, number of pods per plant and plant height will give more emphasis for selecting high yielding genotypes.

- Higher estimates of PCV were observed for number of primary branches, number of pods per plant and seed yield per plant in all the four crosses viz., JAKI 9218 ×

HC -5, A-1 × JG 315, A-1 × HC 5 and JG 11 × JG 24, whereas higher estimates of PCV were observed for 100 seed weight in two crosses viz., A-1 × JG 315 and A-1 × HC 5 of F2 population.

- PCV estimates were moderate for plant height in all the four crosses viz., JAKI 9218 × HC -5, A-1 × JG 315, A-1 × HC 5 and JG 11 × JG 24, and moderate for 100 seed weight in the crosses JAKI 9218 × HC 5 and JG 11 × JG 24.

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