Combining Ability for Yield and Yield Components in Groundnut (*Arachis hypogaea* L.)

"मूँगफली (अरैकिस हाइपोजिया एल.) में उपज एवं उपज घटकों की संयोजन क्षमता

VIJAY SINGH JAT

Thesis

Doctor of Philosophy in Agriculture

(Plant Breeding and Genetics)

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Department of Plant Breeding and Genetics

Rajasthan College of Agriculture

UDAIPUR-313 001 (RAJ.)

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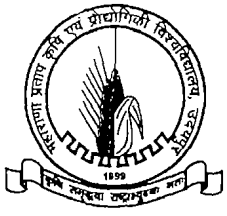

By

VIJAY SINGH JAT

2002

Maharana Pratap University of Agriculture and Technology, Udaipur
Rajasthan College of Agriculture, Udaipur

CERTIFICATE - I

Dated: 26/3/2002

This is to certify that **Mr. Vijay Singh Jat** had successfully completed the Comprehensive/Preliminary Examination held on 20th September, 2001 as required under the regulations for degree of **Doctor of Philosophy in Agriculture**.

(Dr. V.N. Joshi)
Prof. & Head
Department of Plant Breeding & Genetics
Rajasthan College of Agriculture
Udaipur - 313 001 (Raj.)

Rajasthan College of Agriculture
UDAIPUR

Maharana Pratap University of Agriculture and Technology, Udaipur
Rajasthan College of Agriculture, Udaipur

CERTIFICATE -II

Dated: 26/3/2002

This is to certify that this thesis entitled "**Combining ability for yield and yield components in groundnut (*Arachis hypogaea* L.)**", submitted for the degree of **Doctor of Philosophy** in the subject of **Plant Breeding & Genetics,** embodies bonafide research work carried out by **Mr. Vijay Singh Jat** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on 20th March, 2002.

(Dr. V.N. Joshi)
Prof. & Head
Department of Plant Breeding & Genetics

(Dr. B.R. Ranwah)
Major Advisor

(Dr. G.S. Sharma)
Dean
Rajasthan College of Agriculture,
Udaipur (Rajasthan)

Maharana Pratap University of Agriculture and Technology, Udaipur
Rajasthan College of Agriculture, Udaipur

CERTIFICATE -III

Dated: 29 / 7/2002

This is to certify that this thesis entitled **"Combining ability for yield and yield components in groundnut (*Arachis hypogaea* L.)"**, submitted by **Mr. Vijay Singh Jat** to the Maharana Pratap University of Agriculture and Technology, Udaipur in partial fulfilment of the requirements for the degree of **Doctor of Philosophy** in the subject of **Plant Breeding & Genetics** after recommendation by the external examiner was defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination on his thesis has been found satisfactory, we therefore, recommend that the thesis be approved.

29.7.02

(Dr. B.R. Ranwah)
Major Advisor

(Dr. V.N. Joshi)
Advisor

[Dr.(Mrs.) V.L. Mathur]
Advisor

(Dr. V.Nepalia)
Advisor

(Dr. M.S. Shaktawat)
DRI Nominee

(Dr. V.N.Joshi)
Prof. & Head
Department of Plant Breeding & Genetics

External Examiner

Rajasthan College of Agriculture
UDAIPUR

APPROVED

Director
Resident Instructions
Maharana Pratap University of Agriculture & Technology,
Udaipur (Rajasthan)

Maharana Pratap University of Agriculture and Technology, Udaipur

Rajasthan College of Agriculture, Udaipur

CERTIFICATE -IV

Dated: 1 / 8 /2002

This is to certify that **Mr. Vijay Singh Jat** student of the Department of **Plant Breeding & Genetics**, Rajasthan College of Agriculture, Udaipur has made all corrections/ modifications in the thesis entitled **"Combining ability for yield and yield components in groundnut (*Arachis hypogaea* L.)"**, which were suggested by the external examiner and the advisory committee in the oral examination held on 29-7-2002. The final copies of the thesis duly bound and corrected were submitted on 1-8-2002, are enclosed herewith for approval.

1.8.02

(Dr. B.R. Ranwah)
Major Advisor

(Dr. V.N. Joshi)
Prof.& Head
Department of Plant Breeding & Genetics

(Dr. G.S.Sharma)
Dean
Rajasthan College of Agriculture,
Udaipur (Rajasthan)

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Udaipur
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(Vijay Singh Jat)

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1. INTRODUCTION

The cultivated groundnut (*Arachis hypogaea* L.) belongs to the family Papilionaceae under the order Leguminosae. This annual legume is also known as goobernut, monkeynut and peanut. Groundnut is believed to have originated in the southern Bolivia/north West Argentina region in south America (Krapovickas, 1968; Nigam *et al.*, 1994) and comes under self pollinated group (Smith, 1950). It is an allotetraploid (2n = 40, X = 10) having genomes, A and B. But it behaves efficiently as a diploidized tetraploid (Smartt and Stalker, 1982).

Groundnut is divided into two subspecies which differ in their branching pattern; sub sp. *hypogaea* with alternate branching and sub sp. *fastigiata* with sequential branching. Subspecies *hypogaea* is divided into two botanical varieties viz., *hypogaea* (virginia type) and *hirsuta* (peruvian runner type) and sub sp. *fastigiata* into var. *fastigiata* (valencia type) and var. *vulgaris* (spanish type). In present investigation genotypes of var. *vulgaris* were used.

Groundnut ranks 13th in its economic importance among world food crops and is grown all over the world between the latitudes 40°N and 40°S (Gibbons, 1980). The semi–arid and arid regions are most suitable for its cultivation.

India ranks first in area (6.88 m ha) and second in production (6.41 mt) after China in the year 2000–2001. Among oilseeds, groundnut contributes 29.86 per cent area and 35.21 per cent production in the country (Govt. of India, 2001). In Rajasthan, groundnut is cultivated on 195,240 ha area producing 180,320 tonnes of pod with average yield of 924 kg/ha (Govt. of Rajasthan, 2000–2001). Share of Rajasthan in national groundnut area and production is 2.84 and 2.81 per cent, respectively.

In India, groundnut is also known as poorman's 'almond' due to its high quality oil (50%) and a valuable source of inexpensive high quality protein (25%). Major fatty acids present in the groundnut oil are oleic (47.9%), linoleic (29.9%), palmitic (12.6%), arachidic (4.2%), ecosenoic (3.0%) and stearic (1.7%). Groundnut can play an important role in mitigating the nutrient security challenge in India.

In India, 81 per cent groundnut is used for oil extraction, 12 per cent as seed, 6 per cent for direct consumption and 1 per cent for export (Bandyopadhyaya *et al.*, 2000). Besides this, groundnut cake is used as good concentrate for livestock and poultry and haulm as good quality fodder. Importance of groundnut is further enhanced by its potentiality of fixing atmospheric nitrogen to the soil.

The density of oilseed production is considered to be closely linked with groundnut. At present level of demand and contribution of groundnut, by 2020 AD, India will require about 14 mt of groundnut with a growth rate of 2.2 per cent per annum. The increase in production has to come more from increase in productivity and less from increase in area.

Groundnut, the 'King' of oil seeds, has been facing some problems to retain its throne and losing some of its area to other crops. About 87.7 per cent of groundnut area is sown during *kharif* in almost rainfed conditions in areas having erratic rainfall. High cost of cultivation, non–availability of quality seed and lack of early maturing varieties are the bottlenecks of its productivity. For these agroecological situation suitable early maturing, high yielding and drought tolerant varieties are required for obtaining higher yield.

The success of a breeding programme depends primarily upon the proper selection of parents, mating systems employed and finally the breeder's keen judgement in selecting superior genotypes from the more abundant and less desirable plants within the segregating populations. A proper understanding of the nature of inheritance of yield and its

component characters and genetic parameters like heterosis, combining abilitiy etc. are necessary to put such a breeding programme on sound footing (Nagabhushanam *et al.*, 1992). In this direction, line x tester analysis is widely used for testing heterosis and combining ability.

Heterosis is of direct relevance in developing hybrids in cross–pollinated crops, but it is also important in self–pollinated crops. In groundnut, heterotic F_1s had higher frequency of productive derivatives in F_2 and subsequent generations (Pungle, 1983; Makne and Bhale, 1987). Possibility of transgressive segregants further increased if parents of hybrid are diverse in general combining ability (Arunachalam *et al.*, 1984). Hence, estimation of heterosis along with combining ability may be very helpful in selection of parents with good GCA and selection/identification of crosses which can throw desirable transgressive segregants.

In groundnut, pods are formed below the ground level and they can be seen only after harvest. Hence genotypes cannot be screened prior to harvest. Therefore, it is necessary to findout correlation of pod yield with some above ground morphological characters that can be used as selection criteria for improving the pod yield. Partitioning of the correlation coefficient into direct and indirect effects and assessment of the relative importance of each causal factor arfecting the pod yield is also necessary to have precise idea about their relative importance. Keeping all these in view, the present investigation was carried out with following objectives:

1. To study the heterosis, heterobeltiosis and economic heterosis.
2. To estimate the general and specific combining ability.
3. To study the character associations.
4. To identify the crosses which can throw transgressive segregants.

2. REVIEW OF LITERATURE

The present investigation was undertaken to elucidate information on heterosis, combining ability effects and association studies. Efforts have been made to review the available relevant literature on these aspects under following heads :

2.1 Heterosis

2.2 Combining ability

2.3 Correlation studies, and

2.4 Path coefficient analysis.

2.1 Heterosis

Heterosis is of direct interest for developing hybrids in cross–pollinated crops, but also has importance in self–pollinated crops where male sterility is available. In groundnut heterosis cannot be exploited through hybrid varieties due to Cleistogamous and Papilionaceous flower, inadequate supply of pollen grains (Reddy, 1988) and no availability of male sterility. In the absence of male sterility heterotic crosses can be utilised through desirable transgressive segregants in the later generations (Arunachalam *et al.*, 1984). Therefore, hybridization, with emphasis on intra–specific crosses, has often been one of the breeding strategies recommended to increased the productivity in the groundnut (Norden, 1973).

The term 'heterosis' was coined by Shull during 1914 and refers to increase or decrease of the F_1 values from the mid–parent value. Fonesca and Patterson (1968) estimated heterosis over better parent and designated

as heterobeltiosis. Heterosis over parents sometimes not useful because of lower mean values of the parents. To avoid such confusions, if heterosis is measured over standard check will be more useful (Meredith and Bridge, 1972).

Stokes and Hull (1930) observed manifestation of heterosis in different economic traits of groundnut. Since then several workers have studied different hybrids and reported existence of wide array of heterosis.

Heterosis in groundnut is most often observed in crosses between the subspecific groups. Additive genetic variance appears to be of primary importance in crosses made between parents choosen from a single botanical variety, but both additive and non–additive genetic variance was important in crosses made between parents from different botanical varieties, (Wynne and Gregory, 1981). The results of previous investigations for characters under study are as follows :

2.1.1 Days to flowering :

For days to flowering heterosis observed in both the directions and varies from study to study. In negative direction it was ranging from –3.30 to –7.88 per cent (Vyas *et al.*, 2001) and –5.85 to –6.78 per cent (Nagda *et al.*, 2001a) and in positive directions from 20 to 40 per cent (Parker *et al.*, 1970) and 9 to 23 per cent (Arunachalam *et al.*, 1982). Heterosis was higher in Valencia x Virginia crosses than Valencia x Spanish or Varginia x Spanish (Parker *et al.*, 1970).

Heterobeltiosis for early flowering found in Spanish x Spanish (Basu *et al.*, 1986a; Chaudhary *et al.*, 1992), Spanish x Valencia and Spanish x Virginia crosses (Chaudhary *et al.*, 1992). Heterobeltiosis in intervarietal crosses was ranging from –4.35 to –6.21 per cent (Sharma, 2001), –3.68 to –5.59 per cent (Vyas *et al.*, 2001) and –0.58 to –7.91 per cent (Nagda *et*

al., 2001a). Heterobeltiosis was significant in 6 crosses out of 15 (Vyas *et al.*, 2001) and 22 out of 80 crosses (Nagda *et al.*, 2001a).

The economic heterosis for earliness was reported by Nagda *et al.* (2001a), Sharma (2001) and Vyas *et al.* (2001).

2.1.2 Height of main axis :

Negative heterosis was ranging from –6.87 to –35.36 per cent (Vyas *et al.*, 2001) and positive heterosis from 20 to 40 per cent (Parker *et al.*, 1970) whereas Nagda *et al.* (2001a) observed heterosis in both the directions ranging from –60.16 to 21.11 per cent. Heterosis in Valencia x Virginia (Parker *et al.*, 1970), Spanish x Spanish, Spanish x Valencia and Spanish x Virginia crosses (Chaudhary *et al.*, 1992) was also positive. The intra–sub–specific crosses reported superior for plant height (Manoharan *et al.*, 1990). John (1995) observed both positive as well as negative heterosis in Spanish x Valencia crosses.

Nagda *et al.* (2001a) reported range of heterobeltiosis from –1.66 to –50.50 per cent and Vyas *et al.* (2001) –14.70 to –33.95 per cent in the study.

The reduced height of main axis over best check was ranging from –6.25 to –50.10 per cent (Nagda *et al.*, 2001a) and –11.25 to –24.13 per cent (Vyas *et al.*, 2001).

2.1.3 Primary branches per plant :

In a number of studies, positive heterosis was observed (Arunachalam *et al.*, 1982; Nadaf *et al.*, 1988; Chaudhary *et al.*, 1992; Varman and Raveendran, 1997) for primary branches per plant. Vyas *et al.* (2001) observed heterosis from 15.15 to 53.85 per cent whereas in the study of Nagda *et al.* (2001) heterosis was ranged from –2.7 to 48.46 per cent. High

heterosis in the cross ICGS–11 x ICGS–44 (Nadaf *et al.*, 1988) and JL–24 x TAG–24 (Chaudhary *et al.*, 1992) was observed. Heterosis in Valencia x Virginia was also high (Arunachalam *et al.*, 1982) where genotype from Valencia was with high GCA and from Varginia with low GCA.

Hassan and Srivastava (1966) observed heterobeltiosis in Valencia x Virginia cross. Heterobeltiosis was varying from 4.55 to 58.33 per cent (Nagda *et al.*, 2001a) and 23.53 to 53.85 per cent (Vyas *et al.*, 2001).

High economic heterosis in 4 out of 80 crosses (Nagda *et al.*, 2001a) and in 1 out of 15 crosses (Vyas *et al.*, 2001) was reported for primary branches. Economic heterosis ranged from 5 to 15 per cent (Nagda *et al.*, 2001a) while value of economic heterosis was 16.67 per cent in the study of Vyas *et al.* (2001).

2.1.4 Haulm yield per plant :

Swe and Branch (1986) reported positive heterosis in Spanish x Runner type for haulm yield. The heterosis ranging from –28.99 to 104.20 per cent (Nagda *et al.*, 2001a) and –6.87 to –11.87 per cent (Vyas *et al.*, 2001). The number of crosses found significant were 54 out of 80 (Nagda *et al.*, 2001a) and 15 out of 15 (Vyas *et al.*, 2001).

The heterobeltiosis ranging from –9.90 to –17.78 per cent (Nagda *et al.*, 2001a) and –5.09 to –11.60 per cent (Vyas *et al.*, 2001). Vyas *et al.* (2001) reported that 4 crosses were found significant out of 15.

In only one cross economic heterosis (4.36%) was observed out of 15 crosses in the study of Vyas *et al.*, (2001).

2.1.5 Barren pegs per plant :

Basu *et al.* (1986c) reported desirable significant heterosis in negative direction whereas Deshmukh *et al.* (1985) reported positive heterobeltiosis for number of unproductive pegs per plant in all the 4 crosses studied.

2.1.6 Total pods per plant :

Positive heterosis was observed in ICG 511 x ICG 7899 (Nadaf *et al.*, 1988). Heterosis in Spanish x Runner type was also positive (Swe and Branch, 1986).

Heterobeltiosis for more number of total pods per plant was observed in AH 7187 x M–197 (Bansal *et al.*, 1993) and Virginia x Spanish (Garet, 1976; Manoharan *et al.*, 1990).

2.1.7 Mature pods per plant :

Greater heterosis was reported for mature pods per plant (Raju *et al.*, 1979). Range of heterosis in positive direction was reported from 23.33 to 87.50 per cent (Sridharan and Marappan, 1980) and 4.84 to 42.86 per cent (Vyas *et al.*, 2001) whereas heterosis in both the direction ranged from –23.08 to 51.22 per cent (Nagda *et al.*, 2001a). Heterosis in Spanish x Spanish (Sudhakur, 1995) and Virginia x Spanish crosses (Senthil and Vindhiyavarman, 1998) was higher in positive direction whereas, in Spanish x Valencia crosses both positive as well as negative values for heterosis was reported by John (1995).

Heterobeltiosis for mature pods was reported by Deshmukh *et al.* (1985) in four crosses and Bansal *et al.* (1993) in one cross (MK 374 x M–197). The values of heterobeltiosis ranged from 6.22 to 38.40 per cent (Sridharan and Marappan, 1980), 1.37 to 47.62 per cent (Nagda *et al.*, 2001)

and 7.35 to 37.10 per cent (Vyas *et al.*, 2001) for mature pods. Raju (1978) observed 20 per cent heterobeltiosis.

Highly significant heterosis over best check was observed by Sudhakar (1995) in Spanish x Spanish crosses. Range reported for economic heterosis was 1.15 to 10.34 per cent (Nagda *et al.*, 2001a) and 6.41 to 16.67 per cent (Vyas *et al.*, 2001).

2.1.8 Pod yield per plant :

Positive heterosis was recorded (Raju *et al.*, 1979; Isleib and Wynne, 1983; Varman and Raveendran, 1997; Sharma, 2001) for pod yield per plant. Heterosis in positive direction was ranged from 33.44 to 95.33 per cent (Sridharan and Marappan, 1980), 51 to 300 per cent (Arunachalam *et al.*, 1982), 34.72 to 57.28 per cent (Basu *et al.*, 1986c) and 6.07 to 39.64 per cent (Vyas *et al.*, 2001), whereas, Nagda *et al.* (2001a) observed heterosis in both the directions ranging from –15 to 32.81 percent. Positive heterosis was recorded in the cross ICGS–11 x ICGS–4 (Nadaf *et al.*, 1988). Heterosis in two sub–specific groups (Hammons, 1973), in Spanish x Runner type (Basu *et al.*, 1986c), Spanish x Valencia (Reddy and Reddy, 1987) and Spanish x Spanish crosses (Sudhakar, 1995) was positive. Crosses between parents having high and low GCA possessed high heterosis than crosses between parents with high and high and low and low GCA (Arunachalam *et al.*, 1982).

The significant heterobeltiosis (Dwivedi *et al.*, 1989; Bansal *et al.*, 1993; Sharma, 2001) was reported for pod yield. Greater magnitude of heterobeltiosis was found in Spanish x Virginia crosses (Manoharan *et al.*, 1990). Heterobeltiosis was ranged from 4.20 to 70.30 per cent (Sridharan and Marappan, 1980), 7.60 to 8.50 per cent (Varman and Raveendran, 1997), 0.23 to 22.42 per cent (Nagda *et al.*, 2001a) and 7.72 to 37.62 per cent

(Vyas *et al.*, 2001) for pod yield. Raju (1978) observed 37.02 per cent heterobeltiosis. The number of crosses found significant were 35 out of 80 (Nagda *et al.*, 2001a) and 11 out of 15 (Vyas *et al.*, 2001).

The pod yield per plant had significant higher economic heterosis (Sharma, 2001) and it was ranged from 27 to 46 per cent (Patil, 1973), 0.10 to 10.62 per cent (Nagda *et al.*, 2001a) and 6.40 to 12.80 per cent (Vyas *et al.*, 2001). The number of crosses found significant over best check were 7 out of 80 (Nagda *et al.*, 2001a) and 3 out of 15 (Vyas *et al.*, 2001).

2.1.9 Kernel yield per plant :

There was significant positive heterosis (Arunachalam *et al.*, 1982; Isleib and Wynne, 1983) for kernel yield per plant. Swe and Branch (1986) reported positive heterosis in Spanish x Runner type. The positive heterosis varying from 6.38 to 30.20 per cent (Sridharan and Marappan, 1980), 39 to 344 per cent (Arunachalam *et al.*, 1982), 16.16 to 38.41 per cent (Nagda *et al.*, 2001) and 7.95 to 43.72 per cent (Vyas *et al.*, 2001). The number of crosses exhibited significant heterosis were 49 out of 80 (Nagda *et al.*, 2001a) and 13 out 15 (Vyas *et al.*, 2001).

Significant heterobeltiosis for kernel yield per plant was reported by Dwivedi *et al.* (1989) and Bansal *et al.* (1993). The heterobeltiosis ranged from 0.30 to 18.82 per cent (Nagda *et al.*, 2001a) and 8.20 to 33.16 per cent (Vyas *et al.*, 2001). The number of significant crosses reported were 15 out of 80 (Nagda *et al.*, 2001a) and 8 out of 15 (Vyas *et al.*, 2001).

Economic heterosis ranged from 0.29 to 8.99 per cent (Nagda *et al.*, 2001a) and 5.90 to 12.27 per cent (Vyas *et al.*, 2001). The proportions of crosses exhibited significant heterobeltiosis were 5 out of 80 (Nagda *et al.*, 2001a) and 3 out of 15 (Vyas *et al.*, 2001).

2.1.10 Harvest index :

Positive heterosis (Vyas *et al.*, 2001) was reported for harvest index while Swe and Branch (1986) reported negative heterosis in Spanish x Runner type. Both positive as well as negative heterosis was observed in the study of John (1995) and Nagda *et al.* (2001a) . The heterosis ranged from –42.11 to 40.16 per cent (Nagda *et al.*, 2001a) and 4.17 to 25.17 per cent (Vyas *et al.*, 2001). The number of significant crosses were 25 out of 80 (Nagda *et al.*, 2001a) and 8 out of 15 (Vyas *et al.*, 2001).

The heterobeltiosis ranging from 0.21 to 35.89 per cent (Nagda *et al.*, 2001a) and 8.06 to 23.95 per cent (Vyas *et al.*, 2001). The number of significant crosses were 22 out of 80 (Nagda *et al.*, 2001a) and 6 out of 15 (Vyas *et al.*, 2001).

Nagda *et al.* (2001a) reported economic heterosis in 2 out of 80 crosses for harvest index.

2.1.11 Shelling per cent :

Positive heterosis was reported by Arunachalam *et al.* (1982), Basu *et al.* (1986c), Reddy and Reddy (1987), Nadaf *et al.* (1988) and Vyas *et al.* (2001) while negative heterosis was reported by Manoharan *et al.* (1990). Further, heterosis in both the directions was reported by Nagda *et al.* (2001a). Manoharan *et al.* (1990) reported negative heterosis in Spanish x Virginia and Spanish x Spanish crosses. The heterosis ranged from 26 to 63 per cent (Arunachalam *et al.*, 1982), 2.01 to 6.27 per cent (Vyas *et al.*, 2001) and –11.47 to 5.05 per cent (Nagda *et al.*, 2001a). The number of crosses in desired direction were 25 out of 80 (Nagda *et al.*, 2001a) and 8 out of 15 (Vyas *et al.*, 2001).

Garet (1976) observed heterobeltiosis in Virginia x Spanish cross. The heterobeltiosis ranged from 0.47 to 3.81 per cent (Nagda *et al.*, 2001a) and 1.82 to 4.79 per cent (Vyas *et al.*, 2001). The number of crosses with heterobeltiosis were 9 out of 80 (Nagda *et al.*, 2001a) and 2 out of 15 (Vyas *et al.*, 2001).

The economic heterosis was ranging from 0.48 to 4.31 per cent (Nagda *et al.*, 2001a) and 2.42 to 8.21 per cent (Vyas *et al.*, 2001). The number of significant crosses were 14 out of 80 (Nagda *et al.*, 2001a) and 3 out of 15 (Vyas *et al.*, 2001) for shelling per cent.

2.1.12 100–kernel weight :

Positive heterosis (Raju *et al.*, 1979; Arunachalam *et al.*, 1982; Basu *et al.*, 1986c; Reddy and Reddy, 1987; Nadaf *et al.*, 1988; Sudhakar, 1995, Senthil and Vindhiyavarman, 1998; Nagda *et al.*, 2001a; Vyas *et al.*, 2001) was reported for 100–kernel weight. The magnitude of heterosis was 26 to 113 per cent (Arunachalam *et al.*, 1982), 6.07 to 38.85 per cent (Vyas *et al.*, 2001) and –26.69 to 32.06 per cent (Nagda *et al.*, 2001a). The number of crosses with significant heterosis were 55 out of 80 (Nagda *et al.*, 2001a) and 12 out of 15 (Vyas *et al.*, 2001).

Heterobeltiosis was reported by Garet (1976), Varman and Raveendran (1994), Sudhakar (1995), Nagda *et al.* (2001a) and Vyas *et al.* (2001). The heterobeltiosis in Virginia x Spanish (Garet, 1976) and in Spanish x Spanish (Sudhakar, 1995) was observed. The heterobeltiosis ranged from 1.15 to 27.27 per cent (Nagda *et al.*, 2001a) and 6.70 to 27.41 per cent (Vyas *et al.*, 2001). Varman and Raveendran (1994) reported 9.10 per cent heterobeltiosis. The number of crosses with significant heterobeltiosis were 29 out of 80 (Nagda *et al.*, 2001a) and 10 out of 15 (Vyas *et al.*, 2001).

Economic heterosis was reported from 10 to 60 per cent (Patil, 1973), 1.36 to 102.13 per cent (Nagda *et al.*, 2001a) and 6.29 to 39.90 (Vyas *et al.*, 2001).

2.1.13 Oil content :

Positive heterosis (Sudhakar, 1995; Vyas *et al.*, 2001) and heterosis in both the directions (John, 1995; Nagda *et al.*, 2001a) were reported for oil content. The magnitude of heterosis was 2.53 to 5.15 per cent (Vyas *et al.*, 2001) and –3.39 to 6.09 per cent (Nagda *et al.*, 2001a). The number of crosses having desired heterosis were 48 out of 80 (Nagda *et al.*, 2001a) and 9 out of 15 (Vyas *et al.*, 2001)

Heterobeltiosis was reported by Sudhakar (1995), Nagda *et al.* (2001a) and Vyas *et al.* (2001). The heterobeltiosis varied from 0.01 to 5.72 per cent (Nagda *et al.*, 2001a) and 1.74 to 4.39 per cent (Vyas *et al.*, 2001). Further, the number of crosses showed significant heterobeltiosis were 25 out of 80 (Nagda *et al.*, 2001a) and 9 out of 15 (Vyas *et al.*, 2001).

Economic heterosis ranging from 2.0 to 4.0 per cent (Patil, 1973), 0.10 to 5.36 per cent (Nagda *et al.*, 2001a) and 2.59 to 4.71 per cent (Vyas *et al.*, 2001). The number of crosses found significant were 23 out of 80 (Nagda *et al.*, 2001a) and 9 out of 15 (Vyas *et al.*, 2001) for oil content.

2.1.14 Protein content :

Heterosis ranging from –17.83 to 22.08 per cent (Nagda *et al.*, 2001a) and 3.17 to 21.03 per cent (Vyas *et al.*, 2001). The number of crosses having heterosis in desirable direction were 32 out of 80 (Nagda *et al.*, 2001a) and 13 out of 15 (Vyas *et al.*, 2001).

Heterobeltiosis ranged from 18.10 to 18.50 per cent (Makne *et al.*, 1994), 0.22 to 20.45 per cent (Nagda *et al.*, 2001a) and 2.42 to 20.39 per cent

(Vyas *et al.*, 2001). The number of crosses having significant heterobeltiosis were 12 out of 80 (Nagda *et al.*, 2001a) and 12 out of 15 (Vyas *et al.*, 2001).

Economic heterosis was reported by Makne *et al.* (1994), Nagda *et al.* (2001a) and Vyas *et al.* (2001). It ranged from 0.42 to 21.42 per cent (Nagda *et al.*, 2001a) and 2.57 to 15.85 per cent (Vyas *et al.*, 2001). Economic heterosis was significant in 33 out of 45 (Makne *et al.*, 1994), 21 out of 80 (Nagda *et al.*, 2001a) and 12 out of 15 (Vyas *et al.*, 2001) for protein content.

2.1.15 Chlorophyll content :

The heterosis was ranged from 10.66 to 17.07 per cent and significant heterosis was observed in 16 crosses out of 45 crosses (Sharma, 2001).

Heterobeltiosis was ranged from 2.82 to 14.92 per cent and 11 crosses out of 45 were found significant (Sharma, 2001).

Economic heterosis was ranged from 9.07 to 18.69 per cent for chlorophyll content and it was significant in 16 crosses Sharma (2001).

2.2 Combining Ability

The combining ability is defined as "the ability of a strain to produce superior progeny upon hybridization". Sprague and Tatum (1942) refined the concept of combining ability for its practical utility in the evaluation of inbred lines for development of hybrid varieties. They classified combining ability into two categories viz., 'general combining ability' (GCA) representing the average performance of a line in series of crosses, and the 'specific combining ability' (SCA) i.e. deviations of a cross from GCA of its parents". Therefore, the total variation among crosses can be partitioned into two components viz., general and specific combining ability.

Sprague and Tatum (1942) correlated these combining abilities with gene action. The general combining ability of lines is the result of additive and additive x additive gene actions whereas specific combining ability is of non–additive (Rojas and Sprague, 1952; Sprague and Federer, 1952). Falconer (1989) stated that variance due to GCA would be equal to additive variance and SCA would be equal to non–additive variance if lines are homozygous.

Davis (1927) proposed inbred x variety (top cross) approach for evaluating the crosses for combining ability. In 1942, Sprague and Tatum described the use of diallel mating design to determine the relative contribution of GCA and SCA in maize. To estimate GCA and SCA, importance of line x tester (LxT) was realized by Kempthrone (1957).

Diallel random and fix effect model was discussed by Griffing (1956) whereas in LxT random effect model by Kempthrone (1957) and later on Arunachalam (1974) extended it for hybrids evaluating with parents.

In groundnut the genetic parameters had been estimated using diallel cross (Wynne *et al.*, 1970; Garet, 1976; Basu *et al.*, 1986a; Upadhyaya and Nigam, 1994; Varman, 1999), line x tester analysis (Singh, 1983; Upadhyaya *et al.*, 1992; Francies and Ramalingam, 1999; Mathur *et al.*, 2000), half diallel (Makne, 1992) and partial diallel (Sukanya and Gowda, 1996). The comprehensive reviews of studies on combining ability for different characters in groundnut are as follows :

2.2.1 Days to flowering :

Both additive and non–additive gene actions were responsible for inheritance of days to flowering (Basu *et al.*, 1986a). The GCA effects were more important than the SCA effects (Singh *et al.*, 1982; Khanorkar *et al.*,

1984; Kalaimani and Thangavelu, 1996) but reverse trend was also observed (Nagda, 2000; Sharma, 2001).

The parents viz., T–64 and C19–2 (Singh *et al.*, 1982), Chico (Basu *et al.*, 1986b), 91176 (Nigam *et al.*, 1988), Chico and Gangapuri (Upadhyaya and Nigam, 1994) and Co–1 and VRI–1 (Kalaimani and Thangavelu, 1996) were with good GCA effects and cross Ah–114 x 1–2 with good SCA effects (Singh *et al.*, 1982) for early flowering.

2.2.2 Height of main axis :

The role of additive gene action (Sridharan and Marappan, 1980; Manoharan *et al.*, 1985) and additive as well as non–additive gene actions (Basu *et al.*, 1986a) were reported for inheritance of height of main axis.

The preponderance of GCA effects (Singh *et al.*, 1982), SCA effects (Ramakrishanam *et al.*, 1979; Khanorkar *et al.*, 1984; Nagda, 2000; Sharma, 2001) and both GCA as well as SCA effects (Wynne *et al.*, 1970) was reported for height of main axis. The parent R–33–1 (Manoharan *et al.*, 1985) was found a good general combiner for tallness.

2.2.3 Primary branches per plant :

The preponderance of additive gene effects (Habib *et al.*, 1985; Upadhyaya *et al.*, 1992) and equality of both additive and non–additive gene effects (Basu *et al.*, 1986a; Varman *et al.*, 1990) was reported for number of primary branches per plant.

The dominance of GCA effects (Sridharan and Marappan, 1980; Singh and Labana, 1980; Nadaf *et al.*, 1988; Kalaimani and Thangavelu, 1996), SCA effects (Ramakrishnam *et al.*, 1979; Khanorkar *et al.*, 1984; Nagda, 2000; Sharma, 2001) and equal importance of both GCA and SCA effects (Makne, 1992) was found for number of primary branches per plant. The

parents viz., M–145 (Singh and Labana, 1980), ICG–7899 (Nadaf *et al.*, 1988), Shulamit and M–13 (Makne, 1992), ICGS–76 (Senthil and Vindhiyavarman, 1998) and M–13 (Varman and Senthil, 1998) were found good general combiner and the crosses viz., TMV–11 x R–33–1 (Manoharan *et al.*, 1985) and JL–24 x NCAc 17090 (Varman *et al.*, 1990) were good specific combiner for primary branches.

2.2.4 Haulm yield per plant :

The preponderance of SCA effects (Nagda, 2000; Sharma, 2001) was observed for haulm yield per plant.

2.2.5 Total pods per plant :

The additive gene effects (Upadhyaya *et al.*, 1992) and non–additive gene effects (Manoharan *et al.*, 1985; Vindhiyavarman and Raveendran, 1994) were responsible for inheritance of number of total pods per plant. The importance of GCA effects (Garet, 1976; Singh *et al.*, 1982), SCA effects (Labana *et al.*, 1982) and equality of both GCA and SCA effects (Lontical and Abilay, 1992) were reported for inheritance of pods per plant. The parental lines viz., Faizpur 1–5 and M–13 (Singh and Labana, 1980), RSHY–4 (Upadhyaya *et al.*, 1992) and VG–8 (Varman and Raveendran, 1994) with good GCA effects and the crosses viz., TMV–11 x R–33–1 (Manoharan *et al.*, 1985) and ICG 5213 x VR–12 (Varman *et al.*, 1990) with good SCA effects had been identified for number of pods per plant.

2.2.6 Mature pods per plant :

The role of additive gene action (Habib *et al.*, 1985), non–additive gene action (Sandhu and Khehra, 1976; Francies and Ramalingam, 1999; Mathur *et al.*, 2000) and both additive and non–additive gene actions

together (Basu *et al.*, 1986a) were significant for inheritance of number of mature pods per plant.

In case of fixed effect model, the preponderance of the GCA effects (Nadaf *et al.*, 1988), SCA effects (Wynne *et al.*, 1970; Ramakrishnam *et al.*, 1979; Singh and Labana, 1980; Khanorkar *et al.*, 1984; Dwivedi *et al.*, 1989; Nagda, 2000; Sharma, 2001) and equal magnitude of GCA and SCA effects (Makne, 1992) were observed for number of mature pods per plant. The lines with good GCA effects viz., Chandra (Singh *et al.*, 1982), R–33–1 (Manoharan *et al.*, 1985), JL–24 and ICG7899 (Nadaf *et al.*, 1988), Chico (Makne and Bhale, 1989), Chico and R–33–1 (Makne, 1992) and Co–1 and VRI--1 (Kalaimani and Thangavelu, 1996) were identified for mature pods per plant. The crosses with high SCA effects identified for mature pods per plant were TMV–11 x R–33–1 (Manoharan *et al.*, 1985) and ICG 5213 x VR–12 (Senthil and Vindhiyavarman, 1998).

2.2.7 Pod yield per plant :

The preponderance of additive gene action (Sridharan and Marappan, 1980; Manoharan *et al.*, 1985), non–additive gene action (Sandhu and Khehra, 1976; Gibori *et al.*, 1978; Upadhyaya *et al.*, 1992; Vindhiyavarman and Raveendran, 1994; Francies and Ramalingam, 1999; Mathur *et al.*, 2000) and equality of both additive and non–additive gene actions (Basu *et al.*, 1986a; Makne and Bhale, 1989; Sukanya and Gowda, 1996; Rudraswamy *et al.*, 1999) were observed for pod yield per plant.

In case of fixed effect model, the preponderance of GCA effects (Garet, 1976; Singh and Labana, 1980; Singh *et al.*, 1982; Nadaf *et al.*, 1988; Dwivedi *et al.*, 1989) and SCA effects (Wynne *et al.*, 1970; Ramakrishnam *et al.*, 1979; Labana *et al.*, 1982; Singh, 1983; Lontical and Abilay, 1992; Nagda, 2000; Sharma, 2001) were observed.

The lines with good GCA effects viz., Chandra (Singh *et al.*, 1982), AK–12–24 (Singh, 1983), R–33–1 (Manoharan *et al.*, 1985; Basu *et al.*, 1986b; Makne and Bhale, 1989), JL–24 and ICG 7899 (Nadaf *et al.*, 1988), ICGA 86564 (Dwivedi *et al.*, 1989), Tifurn (Holbrook, 1990), NCAc 17090 (Lontical and Abilay, 1992), ICGV 86125 (Upadhyaya *et al.*, 1992), PI 314897, PI 324079 and PI 298845 (Anderson *et al.*, 1993), VG–8 (Varman and Raveendran, 1994), NC–9 (Ali *et al.*, 1995), VG–78 and CS–31 (Kalaimani and Thangavelu, 1996), M–13 (Varman and Senthil, 1998), TMV–10 and TAG –24 (Senthil and Vindhiyavarman, 1998), CO–2 and VR–12 (Francies and Ramalingam, 1999) and ICGV 86325 and Chico (Mathur *et al.*, 2000) and the crosses with high SCA effects viz., TMV–11 x R–33–1 (Manoharan *et al.*, 1985), ALR–1 x CG2178 (Vindhiyavarman and Raveendran, 1994), GSM84–1 x VR–14, M–13 x ALR–2 and TMV–1 x ALR–2 (Varman and Senthil, 1998), ICG 5213 x UR–12 (Senthil and Vindhiyavarman, 1998) and GG–11 x M–30 (Rudraswamy *et al.*, 1999) were identified for pod yield per plant.

2.2.8 Kernel yield per plant :

The predominance of non–additive gene action was observed for kernel yield per plant (Upadhyaya *et al.*, 1992; Francies and Ramalingam, 1999). The SCA effects were greater in magnitude than GCA effects (Wynne *et al.*, 1970; Dwivedi *et al.*, 1989; Lontical and Abilay, 1992; Nagda, 2000; Sharma, 2001) while reverse trend was observed by Garet (1976). The best general combiners identified for kernel yield were AK–12–24 (Singh, 1983), R–33–1 (Makne and Bhale, 1989), Tifurn (Holbrook, 1990), NCAc 17090 (Lontical and Abilay, 1992), ICG 86125 (Upadhyaya *et al.*, 1992), PI 298845 and PI 324079 (Anderson *et al.*, 1993), ICGSE–130 and NC–9 (Ali *et al.*, 1995) and CO–2 (Francies and Ramalingam, 1999).

2.2.9 Harvest index :

The importance of both additive as well as non–additive gene effects was realized for harvest index (Vindhiyavarman and Ravendran, 1994). In case of fixed effect model, the preponderance of GCA effects (Dwivedi *et al.*, 1998) and SCA effects (Nagda, 2000; Sharma, 2001) and equal importance of both GCA and SCA effects (Makne, 1992) was observed. The genotypes with high GCA effects identified for harvest index were Chico and R–33–1 (Makne, 1992), VG–8 (Varman and Raveendran, 1994), CO–1 and VRI–1 (Kalaimani and Thangavelu, 1996) and ICG–2405 (Dwivedi *et al.*, 1998).

2.2.10 Shelling per cent :

The role of additive gene action (Manoharan *et al.*, 1985), non–additive gene action (Varman and Parasivam, 1992; Upadhyaya *et al.*, 1992) and both additive as well as non–additive gene actions (Basu *et al.*, 1986a; Vindhiyavarman and Raveendran, 1994) were observed for inheritance of shelling per cent. The high GCA effects (Kuchanur *et al.*, 1997) and SCA effects (Garet, 1976; Nadaf *et al.*, 1988; Nagda, 2000; Sharma, 2001) were reported for shelling per cent. The lines viz., Chico (Makne and Bhale, 1989), DORG –18–10 and RSHY–13 (Upadhyaya *et al.*, 1992), VG–8 (Varman and Raveendran, 1994), NC–9 (Ali *et al.*, 1995), Dh–40 (Kuchanur *et al.*, 1997), M–13 (Varman and Senthil, 1998) and Chico, VB–42 and VR–60 (Francies and Ramalingam, 1999) were identified with high positive GCA effects.

2.2.11 100–kernel weight :

The role of additive gene action (Sandhu and Khehra, 1976; Sridharan and Marappan, 1980; Manoharan *et al.*, 1985) and additive as well as non–additive gene actions (Basu *et al.*, 1986a; Varman and Parasivam, 1992) were reported for the inheritance of 100–kernel weight.

The preponderance of GCA effects (Garet, 1976; Singh and Labana, 1980; Hamid *et al.*, 1981; Labana *et al.*, 1982; Nadaf *et al.*, 1988; Dwivedi *et al.*, 1989; Kuchanur *et al.*, 1997) and SCA effects (Ramakrishnam *et al.*, 1979, Ali *et al.*, 1995; Nagda, 2000; Sharma, 2001) were observed for 100–kernel weight.

The parents viz., R–33–1 (Basu *et al.*, 1986b), ICG 7899 (Nadaf *et al.*, 1988), ICGA 86564 (Dwivedi *et al.*, 1989), M–13 (Makne and Bhale, 1989), Tifurn (Holbrook, 1990), ICGSE130 (Ali *et al.*, 1995), JL–24 and GBFDS 272 (Kuchanur *et al.*, 1997), TMV–10 and VRI–4 (Senthil and Vindhiyavarman, 1998) and M–13 (Varman and Senthil, 1998) with high GCA effects and the cross ICG 5213 x TAG–24 with high SCA effects (Senthil and Vindhiyavarman, 1998) were identified for 100–kernel weight.

2.2.12 Oil content :

The preponderance of non–additive gene action (Francies and Ramalingam, 1999) was reported for oil content. The predominance of GCA effects (Garet, 1976), SCA effects (Basu *et al.*, 1988; Nagda, 2000; Sharma, 2001) and both GCA and SCA effects (Hamid *et al.*, 1981) were reported for oil content. The lines viz., GAUG–1 and Pollachi (Basu *et al.*, 1988), VRI–1 (Kalaimani and Thamgavelu, 1996) and VB–42 (Francies and Ramalingam, 1999) with high GCA effects and the cross GG–11 x M–30 (Rudraswamy *et al.*, 1999) with high SCA effects were identified for oil content.

2.2.13 Protein content :

The importance of additive and non–additive gene actions (Makne *et al.*, 1994) was reported for protein content. The magnitude of SCA variance was greater than GCA variance (Hamid *et al.*, 1981; Basu *et al.*, 1988; Nagda, 2000; Sharma, 2001). The GAUG–1 and Pollachi (Basu *et al.*, 1988)

and JL–24 (Makne *et al.*, 1994) were identified as parents with high GCA effects.

2.2.14 Chlorophyll content :

The SCA effects were greater in magnitude than GCA effects (Sharma, 2001) for chlorophyll content.

2.3 Correlation Studies

Correlation coefficient is a statistical measure which is used to find out the degree and direction of relationship between two variables. In plant breeding correlation coefficient analysis used to determine the component characters on which selection can be based for genetic improvement in yield and other economic important characters. Correlations with such characters was reported as follows :

2.3.1 Correlation with pod yield :

Pod yield per plant had significant positive correlations with mature pods per plant (Sandhu and Khehra, 1977; Reddy *et al.*, 1986; Deshmukh *et al.*, 1986; Nadaf and Habib, 1989; Vaddoria and Patel, 1992; Bhagat *et al.*, 1993; Sumathi and Ramanathan, 1995). Such relationship was also observed in correlation study of parents and F_1s (Raju *et al.*, 1981; Mahesh Kumar, 1981; Sharma, 2001; Nagda *et al.*, 2001b). Correlation between dry pod yield and kernel yield per plant was also positive (Reddy and Gupta, 1992; Baydar and Bayraktar, 1994; Nagda *et al.*, 1999; Nazzar *et al.*, 2000; Nagda *et al.*, 2000). Similar correlation was observed in study of parents and F_1's Sharma (2001) and Nagda *et al.* (2001b). Similarly, shelling per cent was also having positive correlation with pod yield (Kataria *et al.*, 1984; Reddy and Gupta, 1992; Vaddoria and Patel, 1992; Bhagat *et al.*, 1993; Sharma, 2001; Nagda *et al.*, 2001b).

Correlation of 100–kernel weight with dry pod yield was reported positive (Raju *et al.*, 1981; Yadav *et al.*, 1984; Kataria *et al.*, 1984; Deshmukh *et al.*, 1986; Reddy *et al.*, 1986; Vaddoria and Patel, 1992; Bhagat *et al.*, 1993; Sumathi and Ramnathan, 1995; Salara and Gowda, 1998; Singh and Singh, 1999; Nagda *et al.*, 2000). Positive correlation was also reported in F_1s (Nagda *et al.*, 2001b) and in parents and F_1s (Singh *et al.*, 1984). Reddy and Gupta (1992), Vaddoria and Patel (1992) and Mishra (1995) reported positive correlation between harvest index and pod yield. Such correlation was also reported in F_1s (Sharma, 2001; Nagda *et al.*, 2001b). Total pods per plant also had positive correlation (Bhargava *et al.*, 1970; Singh *et al.*, 1979; Yadav *et al.*, 1984; Alam *et al.*, 1985; Pathirana, 1993; Mishra, 1995; Salara and Gowda, 1998; Singh and Singh, 1999) with pod yield.

Primary branches per plant had positive (Khangura and Sandhu, 1972; Dholaria *et al.*, 1973; Raju *et al.*, 1981; Yadav *et al.*, 1981; and 1984; Nadaf and Habib, 1989; Varman and Raveendran, 1989; Vaddoria and Patel, 1992; Singh and Singh, 1999; Sharma, 2001) and negative in direction (Nagda *et al.*, 2001b) with dry pod yield per plant. Similarly, height of main axis was also had positive (Rao, 1979; Rao, 1978/1979; Alam *et al.*, 1985; Francies and Ramalingam, 1997; Singh and Singh, 1999; Nagda *et al.*, 2000) and negative (Lakshmaiah, 1978; Nagabhushanam, 1981; Mahesh Kumar, 1981; Wu, 1983) correlations.

Likewise, days to 50 per cent flowering had significant positive correlation (Singh and Singh, 1999; Nagda *et al.*, 2000; Jain, 2000) and negative correlation (Deshmukh *et al.*, 1986) with pod yield. Nagda *et al.* (2001b) reported significant negative correlation in parents and positive in F_1s whereas, Sharma (2001) observed negative correlation in F_1s.

Pod yield was positively correlated with oil content (Ali *et al.*, 1996; Nazzar *et al.*, 2000), seed protein (Kundupley, 1977), chlorophyll content (Sharma, 2001), haulm yield (Chandra *et al.*, 1967; Varman and Raveendran, 1989; Jain, 2000) and barren pegs (Rao, 1979; Sumathi and Ramnathan, 1995; Francies and Ramalingam, 1997) whereas it was negatively associated with protein content in F_1s (Sharma, 2001).

2.3.2 Kernel yield per plant :

Kernel yield had positive correlations with pod number (Ibrahim, 1983; Pathirana, 1993; Baydar and Bayraktar, 1994; Bera and Das, 2000), plant height (Uddin *et al.*, 1995), primary branches (Ibrahim, 1983; Uddin *et al.*, 1995), harvest index (Bera and Das, 2000; Jayalakshmi *et al.*, 2000), mature pods (Ibrahim, 1983; Jayalakshmi *et al.*, 2000), pegs (Ibrahim, 1983), oil content (Venkataramana, 2001) and days to 50 per cent flowering (Nagda *et al.*, 2000) whereas it had negative correlations with shelling percent, 100–kernel weight (Uddin *et al.*, 1995) and oil content (Jayalakshmi *et al.*, 2000).

2.3.3 100–kernel weight :

Positive correlation of 100–kernel weight was reported with number of primary branches (Singh *et al.*, 1979; Nagabhushanam, 1981; Vaddoria and Patel, 1992), oil content (Venkataramana, 2001), harvest index (Vaddoria and Patel, 1992), height of main axis (Dorairaj, 1979) and total pods per plant (Singh *et al.*, 1979) whereas, negative correlation also reported with oil content (Ofori, 1996).

2.3.4 Oil content :

Oil content was positively correlated with 100–kernel weight and kernel yield (Venkataramana, 2001), shelling per cent (Sharma, 2001) and mature pods per plant (Nagda, 2000) whereas negatively correlated with kernel yield (Jayalakshmi *et al.*, 2000), 100–kernel weight (Ofori, 1996;

Nagda, 2000), 50 per cent flowering (Nagda, 2000), number of mature and total pods (Shany, 1977) and protein content (Shany, 1977; Nagda, 2000).

2.4 Path Analysis

Standardized partial regression coefficient is known as path coefficient i.e. ratio of standard deviation of cause to the total standard deviation of the effect (Singh and Chaudhary, 1985).The concept of path analysis was originally developed by Wright (1921) but technique was first used for plant selection by Dewey and Lu (1959). In groundnut findings of different authors for path coefficient of pod yield was as follows:

Pod yield was effected directly by kernel yield (Francies and Ramalingam, 1997; Nagda *et al.*, 2000; Bera and Das, 2000; Jain, 2000; Santos RC dos *et al.*, 2000; Sharma, 2001; Nagda *et al.*, 2001b), 100–kernel weight (Deshmukh *et al.*, 1986; Reddy *et al.*, 1986; Vaddoria and Patel, 1992; Nagda *et al.*, 1999; Nagda *et al.*, 2001b), number of mature pods (Sandhu and Khehra, 1977; Raju, 1978; Reddy *et al.*, 1986; Patel and Shelke, 1991; Vaddoria and Patel, 1992; Nagda *et al.*, 2001b), harvest index (Vaddoria and Patel, 1992; Sharma, 2001; Nagda *et al.*, 2001b), primary branches (Chandola *et al.*, 1973· Vaddoria and Patel, 1992), total number of pods (Singh *et al.*, 1979; Jain, 2000), days to flowering (Jain, 2000; Nagda *et al.*, 2001b), haulm yield per plant (Nagda *et al.*, 2001b) and height of main axis (Yadav *et al.*, 1981). Pod yield was indirectly contributed by kernel yield (Francies and Ramalingam, 1997; Jain, 2000; Sharma, 2001), number of mature pods (Raju, 1978), 100–kernel weight (Singh *et al.*, 1984; Jain, 2000), harvest index (Sharma, 2001), number of total pods (Chandola *et al.*, 1973; Sandhu and Khehra, 1977; Jain, 2000), number of primary branches (Chandola *et al.*, 1973) and height of main axis (Yadav *et al.*, 1981).

3. MATERIALS AND METHODS

3.1 Experimental Site

The present investigation entitled "Combining ability for yield and yield components in groundnut (*Arachis hypogaea* L.)" was conducted during *kharif* 2001 at the Instructional Farm, College of Technology and Engineering, Udaipur. Udaipur is situated at an elevation of 582.17 meters above mean sea level at latitude of 24°35' north and longitude of 37°42' East. The meteorological data recorded during the crop period are presented in Appendix - I.

3.2 Experimental Material

The material comprising 12 lines (3 early maturing, 3 medium maturing, two high yielding, one bold seeded, one fresh seed dormant and two drought resistant), 3 testers, their 36 F_1s and two recommended varieties of this zone. The important characters of these genotypes with their pedigree is given in Table 3.1. The 36 F_1s were obtained by crossing 12 lines with 3 testers during *kharif* 2000, at Plant Breeding Research Farm, Rajasthan College of Agriculture, Udaipur. Emasculation, pollination and post-pollination care were carried out according to Kale and Chandra Mouli (1984). Plant protection measures were taken as and when required.

3.3 Crop Husbandry and Experimental Design

The 36 F_1s along with 15 parents and two recommended checks were grown in randomized block design with three replications during *kharif* 2001 with one row of each genotype. The row length was 2.5 meters with row to row and plant to plant spacing of 45 and 15 cm, respectively.

Table 3.1 Description of parents

S. No.	Symbol	Name	Growth habit	Pedigree	Origin	Description
A.	**Lines (Female Parents)**					
1.	L_1	ICUG 92195	SB	ICGV 86055 x ICG (FDRS) 10	AICGIP - Udaipur	Early maturing
2.	L_2	ICUG 92267	SB	ICGV 86155 x ICGV 86162	AICGIP - Udaipur	Early maturing
3.	L_3	ICUG 92217	SB	ICGV 86033 x ICGV 86160	AICGIP - Udaipur	Early maturing
4.	L_4	ICUG 92035	SB	ICGV 86031 x ICG 2214	AICGIP - Udaipur	Medium maturing
5.	L_5	ICUG 92027	SB	ICGV 86302 x ICGV 86460	AICGIP - Udaipur	Medium maturing
6.	L_6	ICGV 92023		ICGV 86309 x ICGV 86448	ICRISAT - Patancheru	Medium maturing
7.	L_7	ICGS 44	SB	Robut 33-1	ICRISAT - Patancheru	High yielding variety also suitable for rabi/summer cultivation
8.	L_8	RG 141	SB	Robut 33-1 x NCAc 2821	A.R.S., Durgapura (Jaipur)	Variety with dark green colour foliage suitable for heavy soils of Rajasthan
9.	L_9	TKG 19A	SB	TG 17 x TG-1	K.K.V. Dapoli	HPS grade bold and attractive kernels suitable for export
10.	L_{10}	ICGS 93470	SB	ICGV 86015 x ICGV 86155	ICRISAT - Patancheru	Early maturing, 3-4 week fresh seed dormancy
11.	L_{11}	DMF 11-23	SB	ICGV 86300 x ICGV 92242	ICRISAT - Patancheru	Drought tolerant variety
12.	L_{12}	DMF 8-22	SB	ICGV 92126 x ICGS 76	ICRISAT - Patancheru	Drought tolerant bold seeded variety
B.	**Testers (Male Parents)**					
1.	T_1	GG-2	SB	J-11 x EC 16659	GAU, Junagadh	High yielding having good shelling percent, also suitable for summer cultivation
2.	T_2	TAG-24	SB	TGS-2 (TG18 x M13) x TGE-1 (Tall mutant x TG-9)	BARC, Trombay	Early maturing, high yielding with 2-3 seeded pod, tolerant to BND, leaf spot and jassid.
3.	T_3	TG-17	SB	Dark green mutant x TG-1	BARC, Trombay	Typical short plant without secondary branches, having increased flowering and pegging, fresh seed dormancy of 3 to 4 weeks.
C.	**Check varieties**					
1.	C_1	SB XI	SB	Ah 4213 x Ah 4354	Jalgaon	Suitable for *kharif* and summer season
2.	C_2	JL-24	SB	EC 94943	Jalgaon	Large dark green leaves, early, smooth pod, compact bearing, widely adapted.

Irrigations were given as and when required. Recommended agronomical practices were followed to raise the successful crop.

3.4 Characters Studied

The observations for all the traits were recorded on 10 randomly selected competitive plants for each genotype in each replication except for days to flowering where observations were recorded on plot basis. A brief description of the procedure adopted for recording the observations for various traits is as under :

3.4.1 Days to flowering :

Number of days were counted from the date of sowing to the date when 50 per cent plants in a plots have at least one flower.

3.4.2 Height of main axis (cm) :

Height of main stem was measured in centimetre from base to the tip of the main stem after uprooting the plant at the time of harvest.

3.4.3 Primary branches per plant :

Total number of primary branches on the main stem were counted after uprooting the plant at the time of harvest.

3.4.4 Haulm yield per plant (g) :

Haulm yield per plant was obtained from 10 randomly selected plants after sun drying and removing the pods. Haulm yield was expressed in grams per plant.

3.4.5 Barren pegs per plant :

Total number of barren pegs which cannot converted into pods and remains aerial were counted after uprooting the plant at the time of harvest.

3.4.6 Total pods per plant :

Total number of pods were counted after uprooting the plant at the time of harvest.

3.4.7 Mature pods per plant :

Total number of mature, fully developed seed bearing pods were counted after uprooting the plant at the time of harvest.

3.4.8 Pod yield per plant (g) :

All the mature pods per plant were detached from individual plant after dried for seven days to standard moisture content, cleaned and weighed in grams on top pan balance.

3.4.9 Kernel yield per plant (g) :

Pods of 10 randomly selected plants were shelled and weight of kernels was recorded in grams.

3.4.10 Harvest index (%) :

Harvest index is the ratio of economic yield (pod yield) to biological yield (total dry matter with pods) and is expressed in percentage. It was calculated as :

$$Harvest\ index\ (\%) = \frac{Pod\ yield}{Pod\ yield + Haulm\ yield} \times 100$$

3.4.11 Shelling per cent :

The shelling percent based on the weight of kernels recovered from the pods sample was calculated as per the formula given below and expressed in per cent.

$$Shelling\ per\ cent = \frac{Weight\ of\ kernels}{Weight\ of\ pods\ sampled} \times 100$$

3.4.12 100-Kernel weight (g) :

Randomly counted three samples of 100 kernels per plot were weighed on digital balance in grams.

3.4.13 Oil content (%) :

The oil content was estimated from a composite sample of kernels from all selected plants of each plots by using specific gravity method (Misra, 1998) and expressed in percentage (Appendix-II).

3.4.14 Protein content (%) :

For chemical analysis of nitrogen, composite sample of kernels from ten selected plants of each plot was taken. Then nitrogen content was estimated by micro-kjeldhal method (Linder, 1944). Value of nitrogen so obtained was converted to crude protein (%) by multiplying with a factor 6.25 (Appendix-III).

3.4.15 Chlorophyll content (mg/g) :

At the time of flowering chlorophyll content was estimated from three representative samples of fully expanded leaves of each plots. The chlorophyll content was estimated by dimethylformamide method (Rani Moran and Dan Porath, 1980; Appendix-IV).

3.4.16 Chlorophyll stability index :

Heat treatment of 65°C for one hrs was given to the another parallel samples running same procedures as followed for estimation of the chlorophyll content and CSI was calculated as follows (Murty and Majumder, 1962).

$$CSI = \frac{Chlorophyll\ in\ heated\ sample}{Chlorophyll\ in\ normal\ sample} \times 100$$

Where, CSI = Chlorophyll stability index

3.5 Statistical Analysis

The plot means of aforesaid characters were subjected to following statistical analysis :

3.5.1 Analysis of variance

3.5.2 Heterosis

3.5.3 Combining ability effects

3.5.4 Correlation studies

3.5.5 Path analysis

3.5.1 Analysis of variance :

The analysis of variance was carried out for randomized block design following the least square technique of Fisher (1925). The skeleton of ANOVA is given in table 3.2. In this ANOVA analysis of hybrids was based on following model :

$$Y_{ijk} = \mu + G_i + G_j + S_{ij} + R_k + \Sigma e_{ijk}$$

3.2 Analysis of variance for experimental design with breakup in different sources

Source	d.f.	SS	MS	EMS	
				Model -I	Model -II
Replications	r-1	$\sum_{j=1}^{r}\left(\sum_{i=1}^{g} X_{ij}\right)^2/g - \left(\sum_{i=1}^{g}\sum_{j=1}^{r} X_{ij}\right)^2/rg$			
Genotypes	g-1	$\sum_{i=1}^{g}\left(\sum_{j=1}^{r} X_{ij}\right)^2/r - \left(\sum_{i=1}^{g}\sum_{j=1}^{r} X_{ij}\right)^2/rg$			
(a) Checks	c-1	$\sum_{i=1}^{c}\left(\sum_{j=1}^{r} X_{ij}\right)^2/r - \left(\sum_{i=1}^{c}\sum_{j=1}^{r} X_{ij}\right)/rc$			
(b) Check v/s parent	1	$\left(\sum_{i=1}^{c}\sum_{j=1}^{r} X_{ij}\right)^2/rc + \left(\sum_{i=1}^{p}\sum_{j=1}^{r} X_{ij}\right)^2/pr - \left(\sum_{i=1}^{c}\sum_{j=1}^{r} X_{ij} + \sum_{i=1}^{p}\sum_{j=1}^{r} X_{ij}\right)^2/(c+p)r$			
(c) Parents	p-1	$\sum_{i=1}^{p}\left(\sum_{j=1}^{r} X_{ij}\right)^2/r - \left(\sum_{i=1}^{p}\sum_{j=1}^{r} X_{ij}\right)^2/rp$			
(i) Testers	t-1	$\sum_{i=1}^{t}\left(\sum_{j=1}^{r} X_{ij}\right)^2/r - \left(\sum_{i=1}^{t}\sum_{j=1}^{r} X_{ij}\right)^2/rt$			
(ii) Lines	l-1	$\sum_{i=1}^{l}\left(\sum_{j=1}^{r} X_{ij}\right)^2/r - \left(\sum_{i=1}^{t}\sum_{j=1}^{r} X_{ij}\right)^2/rl$			
(iii) Line v/s Tester	1	$\sum_{i=1}^{t}\left(\sum_{j=1}^{r} X_{ij}\right)^2 / r + \sum_{i=1}^{l}\left(\sum_{j=1}^{r} X_{ij}\right)^2 / r - \left(\sum_{i=1}^{p}\sum_{j=1}^{r} X_{ij}\right)^2 / rp$			
(d) Parent v/s crosses	1	$\left(\sum_{i=1}^{p}\sum_{j=1}^{r} X_{ij}\right)^2/rp + \left(\sum_{i=1}^{f}\sum_{j=1}^{r} X_{ij}\right)^2/rf - \left(\sum_{i=1}^{p}\sum_{j=1}^{r} X_{ij} + \sum_{i=1}^{f}\sum_{j=1}^{r} X_{ij}\right)^2/(p+f)r$			
(e) Crosses	f-1	$\sum_{i=1}^{f}\left(\sum_{j=1}^{r} X_{ij}\right)^2/r - \left(\sum_{i=1}^{f}\sum_{j=1}^{r} X_{ij}\right)^2/rf$			
(i) T GCA	t-1	$\sum_{i=1}^{t}\left(\sum_{j=1}^{l} Y_{ij}\right)^2/lr - \left(\sum_{i=1}^{t}\sum_{j=1}^{l} Y_{ij}\right)^2/rlt$		$\sigma^2 + \frac{l}{t-1}\sum_{i=1}^{t} TG_i^2$	$\sigma^2+r\sigma^2s+lr\sigma^2_{TG}$
(ii) L GCA	l-1	$\sum_{j=1}^{l}\left(\sum_{i=1}^{t} Y_{ij}\right)^2/tr - \left(\sum_{i=1}^{t}\sum_{j=1}^{l} Y_{ij}\right)^2/rtl$		$\sigma^2 + \frac{t}{l-1}\sum_{j=1}^{l} LG_j^2$	$\sigma^2+r\sigma^2s+tr\sigma^2_{LG}$
(iii) SCA	lt-1	SS cross - SS TGCA - SS LGCA		$\sigma^2 + \frac{r}{lt-1}\sum_{i=1}^{t}\sum_{j=1}^{l} S_{ij}^2$	$\sigma^2+r\sigma^2_S$
3. Error	(r-1) (g-1)	SS total - SSR - SSG		σ^2	σ^2
Total	rg-1	$\sum_{i=1}^{g}\sum_{j=1}^{r} X_{ij}^2 - \left(\sum_{i=1}^{g}\sum_{j=1}^{r} X_{ij}\right)^2/rg$			

[1] c, p, f and g are number of replications, testers, lines, checks, parents i.e. l+t, crosses i.e. lxt and genotypes i.e. c+p+f.

[2] i^{th} replications, Y_{ij} = Sum of over replications for i^{th} tester in j^{th} line i.e. $\sum_{j=1}^{r} X_{ijk}$

Where,

Y_{ijk} = Value of hybrid between i and j^{th} parent in k^{th} replication

μ = General mean

G_i = Effect of i^{th} parent

G_j = Effect of j^{th} parent

S_{ij} = Effect of interaction between i and j^{th} parent

R_k = Effect of k^{th} replication overall genotypes

Σe_{ijk} = Error associated with each plot of experimental design (including parents and checks).

Critical difference :

Critical difference for each character was calculated as follows :

$$SED = \sqrt{\frac{2MSe}{r}}$$

CD 5% = SED x $t_{(r-1)(g-1)}$ at 5% level of significance

CD 1% = SED x $t_{(r-1)(g-1)}$ at 1% level of significance

Coefficient of variation :

$$CV = \frac{\sqrt{MSe}}{\bar{X}} \times 100$$

Where,

MSe = Error mean square

$\bar{X}$ = $\left(\sum_{i=1}^{g} \sum_{j=1}^{r} X_{ij} \right) / rg$

X_{ij} = Mean of i^{th} genotype in j^{th} replication

r = Number of replications

g = Number of genotypes

3.5.2 Estimation of heterosis :

Per cent deviation of F_1 from mid parent and superiority of F_1 over better parent and best check (best performing parent or check for character under reference) has been referred as heterosis, heterobeltiosis and economic heterosis, respectively. Heterosis over mid parent was calculated as per usual procedure, whereas heterobeltiosis and heterosis over best check i.e. economic heterosis were calculated as per procedure given by Fonesca and Patterson (1968) and Meredith and Bridge (1972), respectively. Formulae of their calculations was as follows :

A. $$Heterosis = \frac{(\bar{F}_1 - \bar{MP})}{\bar{MP}} \times 100$$

Its significance was tested by 't' test as follows :

$$t_{[(g-1)(r-1)]} = \frac{Heterosis}{SE_{Het.}}$$

Where,

$$SE_{Het.} = \left[\sqrt{(3MSe/2r)} \; / \; \bar{MP}\right] \times 100$$

B. $$Heterobeltiosis = \frac{\bar{F} - \bar{BP}}{\bar{BP}} \times 100$$

Its significance was tested by 't' test as follows :

$$t_{[(g-1)(r-1)]} = \frac{Heterobeltiosis}{SE_{Hetb.}}$$

Where,

$$SE_{Hetb.} = \left[\sqrt{(2MSe/r)} \ / \ B\bar{P}\right] \times 100$$

C. $$Economic\ Heterosis = \frac{\bar{F}_1 - B\bar{C}}{B\bar{C}} \times 100$$

Its significance was tested by 't' test as follows :

$$t_{[(g-1)\,(r-1)]} = \frac{Economic\ heterosis}{SE_{EH.}}$$

Where,

$$SE_{EH.} = \left[\sqrt{(2MSe/r)} \ / \ B\bar{C}\right] \times 100$$

Where,

$\bar{F}_1$ = Mean value of hybrid

$\bar{MP}$ = $(\bar{P}_1+\bar{P}_2)/2$

$\bar{P}_1$ = Mean value of first parent

$\bar{P}_2$ = Mean value of second parent,

$B\bar{P}$ = Mean value of corresponding better percent in desired direction.

$B\bar{C}$ = Mean value of best standard check, for character under reference

r = Number of replications,

g = Number of genotypes

MSe = Error mean square

Heterobeltiosis and economic heterosis was calculated in positive direction for all the characters except for days to flowering, height of main axis and berren pegs per plant where these were calculated in negative direction.

3.5.3 Combining ability effects :

Using the model referred in analysis of variance individual effects were measured as follows :

$$GCA_{Ti} = \left(\frac{\sum_{j=1}^{l} \sum_{k=1}^{r} Y_{ijk}}{lr} \right) - \left(\frac{\sum_{i=1}^{l} \sum_{j=1}^{t} \sum_{k=1}^{r} Y_{ijk}}{ltr} \right)$$

$$GCA_{Lj} = \left(\frac{\sum_{i=1}^{t} \sum_{k=1}^{r} Y_{ijk}}{tr} \right) - \left(\frac{\sum_{i=1}^{l} \sum_{j=1}^{t} \sum_{k=1}^{r} Y_{ijk}}{ltr} \right)$$

$$SCA_{Gij} = \frac{\sum_{i=1}^{r} Y_{ijk}}{r} - \frac{\sum_{j=1}^{l} \sum_{k=1}^{r} Y_{ijk}}{lr} - \frac{\sum_{i=1}^{t} \sum_{k=1}^{r} Y_{ijk}}{tr} + \frac{\sum_{i=1}^{l} \sum_{j=1}^{t} \sum_{k=1}^{r} Y_{ijk}}{ltr}$$

Standard error of combining ability effects :

SE for GCA of tester

$$S.E.(GCA_{Ti}) = \sqrt{\frac{(t+1)\ MSe}{ltr}}$$

SE for GCA of line

$$S.E.(GCA_{Lj}) = \sqrt{\frac{(l+1)\ MSe}{ltr}}$$

SE for SCA

$$S.E.(SCA_{ij}) = \sqrt{\frac{(lt+l+t+1)\ MSe}{ltr}}$$

SE for difference between GCA of two testers

$$S.E.(GCA_{Ti} - GCA_{Tj}) = \sqrt{\frac{2\ MSe}{lr}}$$

SE for difference between GCA of two lines

$$S.E.(SCA_{Li} - GCA_{Lj}) = \sqrt{\frac{2\ MSe}{tr}}$$

SE for difference between GCA of line and tester

$$S.E.(GCA_{Li} - GCA_{Tj}) = \sqrt{\frac{(t+l)\ MSe}{ltr}}$$

SE for difference between two SCA within tester

$$SE_{SCA_{ij} - SCA_{kj}} = \sqrt{\frac{2(l+1)\ MSe}{lr}}$$

SE for difference between two SCA within line

$$SE_{SCA_{ij} - SCA_{kj}} = \sqrt{\frac{2(t+1)\ MSe}{tr}}$$

SE for difference between any two SCA

$$S.E.(SCA_{ij} - SCA_{kl}) = \sqrt{\frac{2(lt+l+t)\ MSe}{ltr}}$$

Where,

GCA_{Ti}	=	General combining ability of i^{th} tester
GCA_{Li}	=	General combining ability j^{th} line
SCA_{ij}	=	Specific combining ability of hybrid between i^{th} line and j^{th} tester.
Y_{ijk}	=	Mean value of hybrid between i^{th} tester and j^{th} line in k^{th} replications.
t	=	Number of testers
l	=	Number of lines
r	=	Number of replications
MSe	=	Error mean square

3.5.4 Genotypic and phenotypic correlation coefficients :

Correlation coefficients were calculated using variances and covariances. The genotypic and phenotypic correlation between characters were computed using the formula suggested by Fisher (1954) and Al-Jibouri *et al.* (1958) as follows :

(a) Genotypic correlation coefficient between two characters (X) and (Y)

$$r_{XY(g)} = \frac{Cov_{XY(g)}}{\sqrt{V_{X(g)} \times V_{Y(g)}}}$$

(b) Phenotypic correlation coefficient between two characters (X) and (Y)

$$r_{XY(ph)} = \frac{Cov_{XY(ph)}}{\sqrt{V_{X(ph)} \times V_{Y(ph)}}}$$

Where,

$Cov._{XY(g)}$ = Genotypic covariance for X and Y traits

$Cov._{XY(ph)}$ = Phenotypic covariance for X and Y traits.

$Y_{X(g)}$ = Genotypic variance for X traits.

$V_{Y(g)}$ = Genotypic variance for Y traits.

$V_{X(ph)}$ = Phenotypic variance for X traits.

$V_{Y(ph)}$ = Phenotypic variance for Y traits.

Significance of genotypic and phenotypic correlation was tested by the procedure of Mode and Robinson (1959).

3.5.5 Path coefficient analysis :

Path coefficient were calculated using the principles and technique suggested by Wright (1921) and Li (1955) and using the formula given by Dewey and Lu (1959).

Path coefficients were analysed at genotypic level for pod yield per plant by using the characters having significant correlation with pod yield. The direct and indirect effects were obtained as per procedure given below:

Values of P vector of direct effect were obtained as follows :

$$P = C^{-1} R$$

Where,

R is the vector of correlation coefficients between dependent and independent characters.

C^{-1} is the inverse mutual correlation matrix among independent variables.

To obtain the D matrix of direct and indirect effects, C matrix was multiplied with vector P as follows :

$$D = P \times C$$

The residual effect was computed as follows :

$$= \sqrt{1 - \sum_{i=1}^{n} P_i R_i}$$

Where,

P_i = Vector of direct effect

R_i = Vector of correlation coefficients between dependent and independent characters.

n = Number of independent variables

4. EXPERIMENTAL RESULTS

The results of present investigation entitled "Combining ability for yield and yield components in groundnut (*Arachis hypogaea* L.)" are presented under following heads :

4.1 Analysis of variance

4.2 Mean performance

4.3 Heterosis

4.4 Combining ability analysis

4.5 Correlation studies, and

4.6 Path coefficient analysis

4.1 Analysis of Variance (Table 4.1)

Analysis of variance for experimental design revealed significant difference among genotypes for all the character except chlorophyll stability index. When genotypes further partitioned the difference between checks was significant for 100–kernel weight and protein content. The difference between parental and checks mean was significant for days to flowering, barren pegs per plant, kernel yield per plant, harvest index, shelling per cent, oil content and protein content.

Among the parents difference was also significant for all the characters except primary branches per plant. Difference among testers was significant for height of main axis, barren pegs per plant, shelling per cent,

Table 4.1 Analysis of variance for different characters in groundnut

SN	Source of variation	Degree of freedom	Mean squares														
			Days to flowering	Height of main axis	Primary branches per plant	Haulm yield per plant	Barren pegs per plant	Total pods per plant	Mature pods per plant	Pod yield per plant	Kernel yield per plant	Harvest index	Shelling percent	100-Kernel weight	Oil content	Protein content	Chlorophyll content	Chlorophyll stability index
1.	Replications	2	15.18**	58.57**	7.20**	14.63	4.62	61.23**	20.07**	1.34	0.16	23.93	3.80	2.94	0.49	0.74	0.05	234.79
2.	Genotypes	52	15.94**	20.44**	1.64**	44.42**	33.81**	47.74**	24.81**	29.12**	15.34**	89.01**	22.64**	79.69**	13.26**	7.97**	0.03*	178.11
	a. Checks	1	0.17	1.88	0.05	6.00	6.30	8.07	0.038	0.17	0.001	25.01	3.81	19.80**	0.18	4.81*	0.03	36.42
	b. Checks v/s parents	1	33.68**	2.78	0.003	11.24	41.90**	4.65	0.080	2.69	12.61**	57.96**	224.14**	1.24	20.75**	8.23**	0.03	196.14
	c. Parents	14	14.50*	32.72**	0.68	37.85**	54.38**	24.13**	16.86**	17.83**	8.99**	75.17**	25.79**	82.01**	7.59**	9.48**	0.05*	270.14
	I. Testers	2	7.00	6.93**	0.010	9.12	40.28**	8.87	7.09	0.22	0.68	14.40	22.04**	19.86**	1.68	2.49	0.08*	15.20
	II. Lines	11	15.30**	34.95**	0.84	44.84**	52.61**	18.14**	20.17**	22.64**	11.32**	91.19**	28.81**	100.44**	7.72**	11.24**	0.04*	308.80
	III. T v/s L	1	20.67**	59.70**	0.10	4.32	81.17**	120.51**	0.00	0.02	0.01	27.02	0.01	3.63	18.03**	4.07**	0.02	355.49
	d. Parents v/s crosses	1	38.83**	32.52**	17.73**	5.94	3.88	294.75**	54.21**	146.97**	94.92**	200.56**	128.70**	18.99**	45.37**	4.13**	0.02	102.60
	e. Crosses	35	16.27**	16.30**	1.62**	50.00**	26.64**	52.38**	28.46**	31.82**	16.46**	95.34**	15.27**	84.49**	15.15**	7.63**	0.03	145.67
	I. T GCA	2	9.00*	2.02	1.92*	26.51*	8.92**	55.09**	41.09**	18.59**	3.13	107.21**	31.44**	7.46*	13.98**	1.51*	0.03	382.29
	II. L GCA	11	38.75**	38.04**	3.16**	127.85**	47.77**	69.76**	53.78**	75.87**	40.00**	233.35**	29.69**	234.67**	15.17**	15.57**	0.05**	140.30
	III. SCA	22	5.70**	6.72**	0.82*	13.22**	17.68**	43.45**	14.66**	11.00**	5.90**	25.25**	6.59	16.40**	15.25**	4.21**	0.02	123.67
3.	Error	104	2.65	1.07	0.48	6.56	1.98	2.99	2.44	2.14	1.25	11.55	4.98	2.30	0.98	0.38	0.02	181.65

*,** Significant at 5% and 1%, respectively.

100–kernel weight and chlorophyll content and among the lines was significant for all the characters except primary branches per plant.

Difference between parental and crosses means was significant for all the characters except haulm yield per plant, barren pegs per plant and chlorophyll content. Difference between hybrid mean was significant for all the characters except chlorophyll content. When mean performance of hybrids having significant differences averaged for testers, i.e. GCA of tester the difference was significant for all the characters except height of main axis and kernel yield per plant whereas, when the mean performance of hybrids was averaged for lines i.e. GCA of lines, the difference was significant for all the characters. The interaction component of hybrids i.e. SCA was also significant for all the characters except shelling per cent.

4.2 Mean Performance (Table 4.2)

The mean value of all the characters studied are presented in Table 4.2. The character wise results are presented here as under :

4.2.1 Days to flowering :

Analysis of variance revealed that there was non–significant difference in flowering among testers and between checks, whereas among lines earliest flowering was observed in L_{10} (31 days). The flowering of L_7, L_1, L_8 and L_9 was at par to L_{10}. Flowering of T_2, T_1 and both the checks was also at par to the earliest flowering line L_{10}. Among these homozygous genotypes earliest flowering was in L_{10} and T_2. The average performance of hybrids was significantly earlier than the parents. Among hybrids earliest flowering was observed in L_3 x T_1 and L_1 x T_3 (30.33 days). The flowering of other 22 hybrids was at par to above hybrids.

Table 4.2 Mean values for different charecters in groundnut

SN	Genotype	Days to flowering	Height of main axis (cm)	Primary branches per plant	Haulm yield per plant (g)	Barren pegs per plant	Total pods per plant	Mature pods per plant	Pod yield per plant (g)	Kernel yield per plant (g)	Harvest index (%)	Shelling per cent	100-Kernel weight (g)	Oil content (%)	Protein content (%)	Chlorophyll content (mg/g)	Chlorophyll stability index
	T_1	33.00	22.70	4.50	24.80	4.90	30.23	20.90	16.03	10.37	39.26	64.68	38.85	49.70	22.37	0.77	13.49
	T_2	31.00	20.20	4.67	21.33	3.00	32.77	21.73	16.57	10.40	43.62	63.04	39.38	49.10	24.10	1.04	8.99
	T_3	34.00	22.95	4.31	23.39	10.08	29.49	18.75	16.21	9.56	41.06	59.39	34.68	48.21	23.73	0.75	11.37
	L_1	32.33	26.55	4.26	26.53	10.67	24.17	23.07	17.73	10.82	40.19	61.00	36.25	47.36	21.37	0.72	38.60
	L_2	36.67	27.66	3.96	20.60	9.20	22.58	16.72	12.23	6.97	37.37	56.93	31.88	46.66	24.00	0.91	12.56
	L_3	34.33	26.27	4.57	22.07	5.00	28.17	23.77	20.57	12.37	48.21	60.13	40.06	45.92	21.08	0.69	15.15
	L_4	35.67	28.30	4.72	35.23	12.77	26.73	20.98	14.32	8.91	29.04	62.28	35.48	47.26	21.47	0.87	17.25
	L_5	34.33	25.23	4.33	26.25	18.87	27.72	15.78	13.72	8.77	34.29	63.81	39.95	50.89	19.98	0.85	24.40
	L_6	36.00	24.52	5.47	24.64	9.10	30.83	21.24	17.38	10.78	41.35	62.06	38.06	46.90	24.96	0.77	34.09
10	L_7	32.00	19.57	4.83	22.47	4.73	29.73	19.80	15.87	10.26	41.34	66.15	41.24	44.84	25.44	1.03	16.58
11	L_8	32.67	19.67	3.77	22.30	4.17	28.10	24.03	15.30	9.41	40.83	61.52	34.52	46.79	23.16	0.62	4.86
12	L_9	32.67	25.23	4.53	24.00	11.93	24.93	18.77	17.60	11.83	42.36	66.15	49.56	46.47	24.45	0.81	21.16
13	L_{10}	31.00	20.13	5.41	21.77	8.00	25.23	21.53	19.17	12.09	46.75	62.98	43.41	49.20	24.27	0.87	5.82
14	L_{11}	38.33	24.88	4.40	24.73	13.23	24.57	19.00	12.03	7.01	32.76	58.19	27.47	48.10	20.37	0.68	17.26
15	L_{12}	36.33	29.95	5.12	26.74	9.42	28.10	20.78	18.58	12.43	41.01	66.82	42.28	48.66	21.12	0.79	11.89
16	$L_1 \times T_1$	31.67	26.73	4.43	22.00	9.10	35.50	26.97	18.80	12.02	46.05	63.89	37.59	46.34	21.77	0.86	11.54
17	$L_2 \times T_1$	37.00	25.43	5.07	19.27	8.10	27.60	20.73	16.27	10.35	46.05	63.58	35.81	45.18	23.62	0.91	8.98
18	$L_3 \times T_1$	30.33	22.88	4.63	24.75	8.70	30.39	24.60	21.34	13.49	46.24	63.19	38.88	49.66	22.39	0.74	15.43
19	$L_4 \times T_1$	32.33	25.09	4.47	27.37	10.63	30.80	21.35	18.33	11.00	40.33	59.97	38.87	47.63	23.10	0.80	8.29
20	$L_5 \times T_1$	32.67	26.00	4.80	29.37	11.83	31.40	16.93	15.77	9.89	34.81	62.72	43.13	46.28	21.06	0.96	12.32
21	$L_6 \times T_1$	35.67	20.47	5.51	24.89	8.92	26.92	17.67	17.88	11.12	41.89	62.22	36.63	51.20	23.02	0.99	17.29
22	$L_7 \times T_1$	32.00	18.73	4.50	19.83	6.57	32.57	23.53	18.01	11.44	47.72	63.50	40.93	50.82	24.37	0.86	3.83
23	$L_8 \times T_1$	31.67	22.27	4.20	22.17	5.13	31.97	25.50	17.70	11.16	44.71	63.02	37.28	49.25	25.21	0.63	13.93
24	$L_9 \times T_1$	32.33	23.90	5.90	31.54	10.17	28.17	22.87	19.53	12.43	38.35	63.63	45.94	50.50	25.08	0.74	3.84
25	$L_{10} \times T_1$	31.00	19.55	6.10	23.05	11.02	40.18	27.97	24.51	16.45	51.42	67.11	43.25	46.78	24.39	0.83	19.46
26	$L_{11} \times T_1$	36.67	22.37	5.37	24.10	8.92	29.57	20.94	15.42	9.31	38.97	60.37	31.75	44.86	22.35	0.64	14.19
27	$L_{12} \times T_1$	31.67	24.24	6.73	27.22	8.96	39.24	26.88	25.42	17.06	45.06	67.54	43.65	50.24	20.14	0.78	9.10
28	$L_1 \times T_2$	30.67	26.80	4.33	20.77	8.87	39.97	27.87	22.10	14.52	51.69	65.69	38.16	49.24	22.43	0.71	9.15
29	$L_2 \times T_2$	31.67	25.87	5.43	18.37	7.90	26.93	21.03	14.83	9.44	44.91	63.62	32.87	50.89	24.58	0.65	21.50
30	$L_3 \times T_2$	31.00	23.99	4.17	28.60	6.12	31.75	23.92	21.17	13.41	42.50	63.32	40.72	46.75	21.12	0.77	18.27
31	$L_4 \times T_2$	32.33	21.20	4.40	31.35	16.93	29.58	19.87	13.10	8.05	29.76	61.25	35.10	50.02	23.50	0.70	21.88

Continued

Table 4.2 Continued

SN	Genotype	Days to flowering	Height of main axis (cm)	Primary branches per plant	Haulm yield per plant (g)	Barren pegs per plant	Total pods per plant	Mature pods per plant	Pod yield per plant (g)	Kernel yield per plant (g)	Harvest index (%)	Shelling per cent	100-Kernel weight (g)	Oil content (%)	Protein content (%)	Chlorophyll content (mg/g)	Chlorophyll stability index
2	$L_5 \times T_2$	33.00	24.62	5.45	31.33	18.98	28.49	19.44	18.01	11.81	36.53	65.52	40.73	53.03	24.66	0.87	43.74
3	$L_6 \times T_2$	33.33	21.97	5.32	24.20	5.80	30.56	21.90	21.25	13.54	46.76	63.70	41.48	50.57	21.06	0.84	16.44
4	$L_7 \times T_2$	31.67	20.02	5.97	18.31	9.20	31.23	18.68	17.66	11.29	49.15	63.94	39.98	48.99	26.16	0.85	10.44
5	$L_8 \times T_2$	31.00	23.92	4.94	22.39	5.40	30.56	22.19	17.57	11.93	44.11	67.75	37.02	49.20	23.08	0.64	17.42
6	$L_9 \times T_2$	30.67	22.11	6.77	27.69	10.72	27.83	20.16	19.71	12.45	41.91	63.17	43.40	46.72	23.75	0.80	9.42
7	$L_{10} \times T_2$	31.00	20.75	5.73	18.46	8.10	25.54	20.58	20.58	13.80	52.76	67.14	45.37	45.85	25.92	0.92	15.14
8	$L_{11} \times T_2$	38.33	22.48	5.20	24.43	14.20	26.67	17.07	13.53	8.31	35.13	61.23	25.95	48.19	22.96	0.78	10.06
9	$L_{12} \times T_2$	34.33	28.43	5.60	24.40	6.87	30.71	21.55	21.17	14.08	46.51	66.51	42.22	50.41	21.43	0.95	21.18
0	$L_1 \times T_3$	30.33	25.50	4.27	27.46	9.13	35.70	26.20	20.80	13.98	43.13	67.18	34.74	52.55	22.33	0.65	16.53
1	$L_2 \times T_3$	33.00	23.01	5.49	19.40	6.44	26.33	19.90	11.80	8.01	37.83	67.75	34.68	45.93	23.89	0.81	17.53
2	$L_3 \times T_3$	31.67	25.78	4.64	28.83	11.62	26.20	20.06	20.47	13.32	41.48	65.07	42.84	50.95	20.41	0.66	16.90
3	$L_4 \times T_3$	34.67	25.52	5.82	31.77	11.33	24.40	20.40	14.80	9.31	31.86	62.65	32.37	51.13	24.06	0.73	12.77
4	$L_5 \times T_3$	32.33	23.59	6.00	29.80	10.97	32.02	19.47	16.32	10.23	35.91	62.81	42.14	51.59	23.64	0.92	14.88
5	$L_6 \times T_3$	34.33	21.52	6.26	28.34	8.66	40.03	24.71	22.72	15.29	44.50	67.42	41.96	47.80	22.52	0.71	22.31
6	$L_7 \times T_3$	35.67	18.95	5.97	22.17	5.30	25.89	17.67	14.51	9.36	39.43	64.66	38.53	51.69	21.35	0.84	16.38
7	$L_8 \times T_3$	32.33	23.75	5.40	26.73	10.27	30.37	24.17	20.07	13.77	42.83	68.49	36.26	46.99	23.66	0.69	16.10
8	$L_9 \times T_3$	31.67	22.89	6.32	26.17	7.76	29.54	19.47	17.92	11.40	40.77	63.50	42.53	45.69	26.06	0.75	13.87
9	$L_{10} \times T_3$	32.33	22.17	5.89	19.87	8.83	30.36	21.81	18.85	12.11	48.60	64.15	48.17	48.11	24.33	0.84	16.89
0	$L_{11} \times T_3$	40.33	21.33	6.04	25.53	11.41	27.62	17.87	12.83	7.99	33.30	62.51	24.78	49.75	22.89	0.73	20.29
1	$L_{12} \times T_3$	32.33	22.89	5.01	24.08	7.90	29.11	21.54	20.64	13.87	46.15	66.95	47.49	50.79	21.14	0.77	6.31
2	Check 1	31.33	22.97	4.53	24.00	7.22	29.65	20.66	17.10	11.66	41.23	68.05	40.51	49.86	23.14	0.81	25.45
3	Check 2	31.67	24.09	4.70	22.00	5.17	27.33	20.50	16.77	11.69	45.31	69.64	36.87	49.58	24.93	0.67	20.52
	Gen. mean	33.18	23.54	5.10	24.70	9.14	29.66	21.35	17.71	11.36	41.79	63.95	38.75	48.62	23.08	0.79	15.91
	Par. mean	34.02	24.25	4.59	24.46	9.01	27.56	20.46	16.22	10.13	39.96	62.34	38.21	47.74	22.79	0.81	16.90
	F_1 mean	32.92	23.24	5.34	24.89	9.35	30.60	21.76	18.37	11.86	42.48	64.35	38.98	48.93	23.15	0.79	15.10
	Ch. mean	31.50	23.53	4.61	23.00	6.19	28.49	20.58	16.93	11.67	43.27	68.84	38.67	49.71	24.03	0.74	22.98
	Se	0.94	0.60	0.40	1.48	0.81	1.00	0.90	0.84	0.65	1.96	1.29	0.88	0.57	0.36	0.08	7.78
	CD5%	2.64	1.68	1.12	4.15	2.28	2.80	2.53	2.37	1.81	5.50	3.61	2.46	1.60	1.00	0.23	-
	CD1%	3.49	2.22	1.48	5.49	3.02	3.71	3.35	3.13	2.40	7.28	4.78	3.25	2.12	1.32	0.31	-
	CV	4.91	4.40	13.58	10.37	15.41	5.83	7.32	8.26	9.84	8.13	3.49	3.91	2.04	2.66	18.18	84.73

4.2.2 Height of main axis :

The difference between height of main axis of checks was non–significant. The average height of parents was also at par to the average height of checks. Minimum height of main axis was observed in T_2 (20.20 cm) among testers and in L_7 (19.57 cm) among lines. Height of L_8 (19.67 cm) and L_{10} (20.13 cm) was at par to L_7. Among the parents and checks minimum height of main axis was in L_7. Average height of hybrids was significantly lower than the parents. Among hybrids minimum height was observed in $L_7 \times T_1$ (18.73 cm). The height of main axis of $L_7 \times T_3$ (18.95 cm), $L_{10} \times T_1$ (19.55 cm) and $L_7 \times T_2$ (20.02 cm) was at par to the cross $L_7 \times T_1$.

4.2.3 Primary branches per plant :

The number of primary branches per plant was at par in checks and parents. However, numerically maximum branches were observed in line L_6 (5.47). Average primary branches per plant in hybrids was significantly higher than the average of parents. Among the hybrids, maximum number of primary branches was beared by the cross $L_9 \times T_2$ (6.77). Other 13 hybrids were also at par to this cross.

4.2.4 Haulm yield per plant :

In both the checks difference between haulm yield per plant was non–significant and was at par to average of parents. Similarly, difference in haulm yield of testers was also non–significant. However, among the lines maximum haulm yield was recorded in L_4 (35.23 g). Haulm yield of this line was also maximum among all homozygous lines. Among the hybrids maximum haulm yield was in $L_4 \times T_3$ (31.77 g). Haulm yield of other nine hybrids were also at par to this cross.

4.2.5 Barren pegs per plant :

Both the checks having equal number of barren pegs per plant and was significantly less than the average of parents. The minimum number of barren pegs was in T_2 (3.0). The number of barren pegs in T_1 (4.90) was at par to T_2. Among the lines minimum number of barren pegs was observed in L_8 (4.17). Number of barren pegs in L_3 and L_7 was at par to L_8. Therefore, among homozygous lines minimum barren pegs were in T_2 (3.0). Among hybrids $L_8 \times T_1$ (5.13) had minimum number of barren pegs per plant. Number of barren pegs in $L_7 \times T_3$ (5.30), $L_8 \times T_2$ (5.40), $L_6 \times T_2$ (5.80), $L_3 \times T_2$ (6.12), $L_2 \times T_3$ (6.44), $L_7 \times T_1$ (6.57) and $L_{12} \times T_2$ (6.87) were at par to $L_8 \times T_1$.

4.2.6 Total pods per plant :

In both the checks total pods per plant was equal and at par to average of parents. Difference among testers was non–significant. However, among lines highest total pods per plant was recorded in L_6 (30.83). The total pods per plant in L_7, L_3, L_8 and L_{12} was at par to L_6. Among all homozygous genotypes maximum pods were observed in T_2 (32.77). Among the hybrids $L_{10} \times T_1$ (40.18) beared largest number of total pods per plant. Total pods in $L_6 \times T_3$, $L_1 \times T_2$ and $L_{12} \times T_1$ were at par to the above hybrid.

4.2.7 Mature pods per plant :

Mature pods per plant in checks were at par to each other. Difference between average performance of checks and parents was non–significant. Similarly, mature pods in all the three testers was also at par to each other. Among lines L_8 (24.03) had maximum number of mature pods. This number was highest among all homozygous genotypes. L_1, L_3 and L_{10} were at par to L_8.

Average mature pods in hybrids was significantly higher than average of parents. Among hybrids highest number of mature pods was observed in L_{10} x T_1 (27.97). Mature pods in L_1 x T_2 (27.87), L_1 x T_1 (26.97) L_{12} x T_1 (26.88), L_1 x T_3 (26.20) and L_8 x T_1 (25.50) was at par to L_{10} x T_1.

4.2.8 Pod yield per plant :

Pod yield per plant was following the same trend of mature pods per plant. Difference in means between both the checks, checks and parents and among testers was non–significant. Among all homozygous genotypes L_3 (20.57 g) had highest pod yield per plant. Pod yield of L_{10} and L_{12} was at par to L_3. Average pod yield of hybrids was significantly higher than the parents. Among crosses highest pod yield per plant was recorded in L_{12} x T_1 (25.42 g). Pod yield in L_{10} x T_1 was at par to this cross.

4.2.9 Kernel yield per plant :

Difference in means between checks and among testers was non–significant. However, average kernel yield of checks was significantly higher than the parents. Among all the homozygous genotypes, maximum kernel yield was observed in L_{12} (12.43 g). Kernel yield of L_1, L_3, L_6, L_9 and L_{10} was at par to L_{12}. Average kernel yield of hybrids was significantly higher than the parents. Among hybrids, L_{12} x T_1 (17.06 g) had highest kernel yield per plant and two cross viz., L_{10} x T_1 (16.45 g) and L_6 x T_3 (15.29 g) were at par to the cross L_{12} x T_1.

4.2.10 Harvest index :

There was no significant difference in harvest index between checks and among testers. However, harvest index was higher in checks than parents. Among parents and checks maximum harvest index was observed in L_3 (48.21%). Harvest index of L_{10} (46.75%) was at par to L_3. The average

harvest index of hybrids was significantly higher than the parents. Harvest index of L_{10} x T_2 (52.76%) was highest among crosses. Other hybrids having harvest index at par to L_{10} x T_2 were L_1 x T_2 (51.69 %), L_{10} x T_1 (51.42 %), L_7 x T_2 (49.15 %), L_{10} x T_3 (48.60 %) and L_7 x T_1 (47.72%).

4.2.11 Shelling per cent :

Shelling per cent was equal in both the checks but was higher than the parents. Among testers T_1 (64.68) had highest shelling per cent and T_2 (63.04) was at par to T_1. Among the lines L_{12} (66.82) was having highest shelling per cent. Other lines having shelling per cent at par to L_{12} were L_5, L_7 and L_9. Among parents and checks maximum shelling per cent was in JL–24 (69.64). Average shelling per cent of hybrids was significantly higher than the parents. The cross L_8 x T_3 (68.49) had the highest shelling per cent among the hybrids. Twelve other hybrids were also having shelling per cent at par to L_8 x T_3. None of the hybrid was superior than the best check JL–24.

4.2.12 100–Kernel weight :

SB–XI had significantly higher 100–kernel weight than JL–24. Average 100–kernel weight of checks and parents was equal. Among the testers, T_2 (39.38 g) had highest 100–kernel weight and T_1 (38.85 g) was at par to it. Among lines, highest 100–kernel weight was observed in L_9 (49.56 g) and was maximum among parents and checks. Average 100–kernel weight of hybrids was significantly higher than the average of parents. Among the hybrids maximum 100–kernel weight was observed in L_{10} x T_3 (48.17 g). Kernels of L_{12} x T_3 were also as bold as in L_{12} x T_3. None of the cross exceeded the limit of parental value L_9 (49.56 g).

4.2.13 Oil content :

There was non–significant difference for oil content between checks and among testers. Among lines L_5 had highest oil content (50.89%). The average oil content of checks and hybrids was significantly superior than the average of parents. Among hybrids L_5 x T_2 (53.03%) had highest oil content and other three hybrids viz., L_1 x T_3, L_5 x T_3 and L_7 x T_3 were also at par to it.

4.2.14 Protein content :

Protein content in JL–24 was significantly higher than SB–XI and average of both was higher than the average of parents. Protein content in testers was at par to each other but, among lines L_7 (25.44 %) had highest protein content. Protein content in L_6 and L_9 were at par to L_7. Average protein content in crosses was higher than the parental average. The L_7 x T_2 (26.16%) possessed highest value of protein content among hybrids. Protein content in L_9 x T_3, L_{10} x T_2, L_8 x T_1 and L_9 x T_1 was also high as in L_7 x T_2.

4.2.15 Chlorophyll content (mg/g) :

Both the checks having equal chlorophyll content and was at par to average of parents. Among the testers T_2 (1.04 mg/g) and among the lines L_7 (1.03 mg/g) had highest chlorophyll content. Other lines having high chlorophyll content were L_2, L_4, L_{10}, L_5 and L_9. Chlorophyll content in hybrids was at par to each other.

4.2.16 Chlorophyll stability index :

Chlorophyll stability index was the most variable character and highly influenced by the environmental conditions having coefficient of variation 84.73 per cent. On account of this all genotypes were at par to

each other. However, it was ranged from 4.86 per cent (L_8) to 38.60 per cent (L_1).

4.3 Heterosis

The heterosis as per cent deviation of hybrid from its mid–parental value and heterobeltiosis and economic heterosis, as per cent superiority of hybrid over its better parent and best check (best performing parents/checks for character under reference), respectively. The magnitude of heterosis, heterobeltiosis and economic heterosis along with their standard errors are presented in table 4.3.1 to 4.3.16. The significant findings for characters having significant genotypic difference were as follows :

4.3.1 Days to flowering (Table 4.3.1) :

The estimates of heterosis revealed that out of 9 significant heterotic hybrids, 3 were having positive heterosis and 6 were negative. Highest heterosis for early flowering was – 9.90 per cent (L_3 x T_1) and for late flowering it was 11.52 per cent (L_{11} x T_3).

The heterobeltiosis for earliness was significant in one cross viz., L_3 x T_1 (–8.08 %) but economic heterosis was not significant in any cross.

4.3.2 Height of main axis (Table 4.3.2) :

For height of main axis 19 hybrids exhibited significant heterosis. Eight hybrids having positive heterosis and 11 hybrids were having negative heterosis. Maximum value of heterosis for dwarfness was –13.44 per cent (L_{12} x T_3) and for tallness was 20.00 per cent (L_8 x T_2).

Heterobeltiosis for reduced height of main axis was observed in cross L_6 x T_1 (–9.82 %) but, economic heterosis was not significant in any cross.

Table 4.3.1 **Extent of heterosis, heterobeltiosis and economic heterosis for days to flowering**

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	$L_1 \times T_1$	-3.06	3.52	-2.06	4.11	-	-
2.	$L_2 \times T_1$	6.22	3.30	-	-	-	-
3.	$L_3 \times T_1$	-9.90**	3.42	-8.08*	4.03	-2.15	4.29
4.	$L_4 \times T_1$	-5.83	3.35	-2.02	4.03	-	-
5.	$L_5 \times T_1$	-2.97	3.42	-1.01	4.03	-	-
6.	$L_6 \times T_1$	3.38	3.34	-	-	-	-
7.	$L_7 \times T_1$	-1.54	3.54	0.00	-	-	-
8.	$L_8 \times T_1$	-3.55	3.51	-3.06	4.07	-	-
9.	$L_9 \times T_1$	-1.52	3.51	-1.02	4.07	-	-
10.	$L_{10} \times T_1$	-3.12	3.60	0.00	-	0.00	-
11.	$L_{11} \times T_1$	2.80	3.23	-	-	-	-
12.	$L_{12} \times T_1$	-8.65*	3.32	-4.04	4.03	-	-
13.	$L_1 \times T_2$	-3.16	3.64	-1.08	4.29	-1.08	4.29
14.	$L_2 \times T_2$	-6.40	3.40	-	-	-	-
15.	$L_3 \times T_2$	-5.10	3.52	0.00	-	0.00	-
16.	$L_4 \times T_2$	-3.00	3.45	-	-	-	-
17.	$L_5 \times T_2$	1.02	3.52	-	-	-	-
18.	$L_6 \times T_2$	-0.50	3.44	-	-	-	-
19.	$L_7 \times T_2$	0.53	3.65	-	-	-	-
20.	$L_8 \times T_2$	-2.62	3.62	0.00	-	0.00	-
21.	$L_9 \times T_2$	-3.66	3.62	-1.08	4.29	-1.08	4.29
22.	$L_{10} \times T_2$	0.00	3.71	0.00	-	0.00	-
23.	$L_{11} \times T_2$	10.58**	3.32	-	-	-	-
24.	$L_{12} \times T_2$	1.98	3.42	-	-	-	-
25.	$L_1 \times T_3$	-8.54*	3.47	-6.19	4.11	-2.15	4.29
26.	$L_2 \times T_3$	-6.60*	3.26	-2.94	3.91	-	-
27.	$L_3 \times T_3$	-7.32*	3.37	-6.86	3.91	-	-
28.	$L_4 \times T_3$	-0.48	3.30	-	-	-	-
29.	$L_5 \times T_3$	-5.37	3.37	-4.90	3.91	-	-
30.	$L_6 \times T_3$	-1.90	3.29	-	-	-	-
31.	$L_7 \times T_3$	8.08*	3.49	-	-	-	-
32.	$L_8 \times T_3$	-3.00	3.45	-1.02	4.07	-	-
33.	$L_9 \times T_3$	-5.00	3.45	-3.06	4.07	-	-
34.	$L_{10} \times T_3$	-0.51	3.54	-	-	-	-
35.	$L_{11} \times T_3$	11.52**	3.18	-	-	-	-
36.	$L_{12} \times T_3$	-8.06*	3.27	-4.90	3.91	-	-

*,** Significant at 5% and 1%, respectively.

Table 4.3.2 **Extent of heterosis, heterobeltiosis and economic heterosis for height of main axis**

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	$L_1 \times T_1$	8.55**	2.98	-	-	-	-
2.	$L_2 \times T_1$	1.00	2.91	-	-	-	-
3.	$L_3 \times T_1$	-6.54*	2.99	-	-	-	-
4.	$L_4 \times T_1$	-1.61	2.87	-	-	-	-
5.	$L_5 \times T_1$	8.50**	3.06	-	-	-	-
6.	$L_6 \times T_1$	-13.31**	3.10	-9.82**	3.73	-	-
7.	$L_7 \times T_1$	-11.36**	3.47	-4.26	4.32	-4.26	4.32
8.	$L_8 \times T_1$	5.11	3.46	-	-	-	-
9.	$L_9 \times T_1$	-0.28	3.06	-	-	-	-
10.	$L_{10} \times T_1$	-8.72*	3.42	-2.90	4.20	-0.09	4.32
11.	$L_{11} \times T_1$	-5.98	3.08	-1.45	3.73	-	-
12.	$L_{12} \times T_1$	-7.91**	2.78	-	-	-	-
13.	$L_1 \times T_2$	14.65**	3.13	-	-	-	-
14.	$L_2 \times T_2$	8.09**	3.06	-	-	-	-
15.	$L_3 \times T_2$	3.27	3.15	-	-	-	-
16.	$L_4 \times T_2$	-12.58**	3.02	-	-	-	-
17.	$L_5 \times T_2$	8.38*	3.23	-	-	-	-
18.	$L_6 \times T_2$	-1.75	3.28	-	-	-	-
19.	$L_7 \times T_2$	0.67	3.68	-	-	-	-
20.	$L_8 \times T_2$	20.00**	3.68	-	-	-	-
21.	$L_9 \times T_2$	-2.66	3.22	-	-	-	-
22.	$L_{10} \times T_2$	2.89	3.63	-	-	-	-
23.	$L_{11} \times T_2$	-0.26	3.25	-	-	-	-
24.	$L_{12} \times T_2$	13.39**	2.92	-	-	-	-
25.	$L_1 \times T_3$	3.04	2.96	-	-	-	-
26.	$L_2 \times T_3$	-9.08**	2.90	-	-	-	-
27.	$L_3 \times T_3$	4.77	2.98	-	-	-	-
28.	$L_4 \times T_3$	-0.42	2.86	-	-	-	-
29.	$L_5 \times T_3$	-2.08	3.04	-	-	-	-
30.	$L_6 \times T_3$	-9.33**	3.09	-6.22	3.69	-	-
31.	$L_7 \times T_3$	-10.85**	3.45	-3.15	4.32	-3.15	4.32
32.	$L_8 \times T_3$	11.47**	3.44	-	-	-	-
33.	$L_9 \times T_3$	-4.98	3.04	-0.25	3.69	-	-
34.	$L_{10} \times T_3$	2.91	3.40	-	-	-	-
35.	$L_{11} \times T_3$	-10.82**	3.06	-7.06	3.69	-	-
36.	$L_{12} \times T_3$	-13.44**	2.77	-0.23	3.69	-	-

*,** Significant at 5% and 1%, respectively.

4.3.3 Primary branched per plant (Table 4.3.3) :

Significant heterosis in positive direction was observed in 15 crosses with range from 21.19 per cent (L_{10} x T_9) to 47.10 per cent (L_9 x T_2).

The maximum heterobeltiosis for number of primary branches was 45.00 per cent (L_9 x T_2). Eight other crosses also exhibited significant heterobeltiosis with a minimum heterobeltiosis 23.45 per cent (L_7 x T_2 and L_7 x T_3).

Economic heterosis was significant in two hybrids viz., L_9 x T_2 (23.78 %) and L_{12} x T_1 (23.17 %).

4.3.4 Haulm yield per plant (Table 4.3.4) :

Heterosis for haulm yield per plant was ranged from –16.41 per cent (L_7 x T_2) to 31.80 per cent (L_3 x T_2). Heterosis for more haulm yield was significant in 9 crosses whereas, for less haulm yield in 3 crosses.

Four hybrids revealed significant heterobeltiosis for haulm yield per plant with a range from 19.37 per cent (L_5 x T_2) to 29.61 per cent (L_3 x T_2). None of the hybrid depicted economic heterosis for this trait.

4.3.5 Barren pegs per plant (Table 4.3.5) :

Heterosis in negative direction was significant in 4 hybrids varied from –24.20 per cent (L_5 x T_3) to –33.18 per cent (L_7 x T_2). Significant positive heterosis was observed in 12 hybrids. Magnitude of heterosis in these crosses was ranging from 29.76 per cent (L_1 x T_2) to 137.93 per cent (L_7 x T_2).

Two hybrids viz., L_9 x T_3 (–23.02 %) and L_2 x T_3 (–29.97 %) revealed significant heterobeltiosis for less number of barren pegs per plant. None of hybrid showed economic heterosis for this trait.

Table 4.3.3 **Extent of heterosis, heterobeltiosis and economic heterosis for primary branches per plant**

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	L_1 x T_1	1.26	11.18	-	-	-	-
2.	L_2 x T_1	19.78	11.57	12.59	12.56	-	-
3.	L_3 x T_1	2.21	10.80	1.46	12.38	-	-
4.	L_4 x T_1	-3.07	10.62	-	-	-	-
5.	L_5 x T_1	8.72	11.09	6.67	12.56	-	-
6.	L_6 x T_1	10.64	9.82	0.85	10.34	0.85	10.34
7.	L_7 x T_1	-3.57	10.49	-	-	-	-
8.	L_8 x T_1	1.61	11.84	-	-	-	-
9.	L_9 x T_1	30.63**	10.84	30.15*	12.47	7.93	10.34
10.	L_{10}x T1	23.18*	9.88	12.82	10.45	11.65	10.34
11.	L_{11} x T1	20.55	11.00	19.26	12.56	-	-
12.	L_{12}x T1	39.94**	10.17	31.42**	11.03	23.17*	10.34
13.	L_1 x T_2	-2.88	10.97	-	-	-	-
14.	L_2 x T_2	25.97*	11.35	16.43	12.11	-	-
15.	L_3 x T_2	-9.75	10.60	-	-	-	-
16.	L_4 x T_2	-6.22	10.44	-	-	-	-
17.	L_5 x T_2	21.08	10.88	16.71	12.11	-	-
18.	L_6 x T_2	4.93	9.66	-	-	-	-
19.	L_7 x T_2	25.61*	10.31	23.45*	11.70	9.15	10.34
20.	L_8 x T_2	17.08	11.61	5.79	12.11	-	-
21.	L_9 x T_2	47.10**	10.64	45.00**	12.11	23.78*	10.34
22.	L_{10}x T2	13.79	9.72	5.98	10.45	4.88	10.34
23.	L_{11} x T2	14.66	10.80	11.43	12.11	-	-
24.	L_{12}x T2	14.40	10.00	9.30	11.03	2.44	10.34
25.	L_1 x T_3	-0.39	11.43	-	-	-	-
26.	L_2 x T_3	32.85**	11.84	27.46*	13.12	0.49	10.34
27.	L_3 x T_3	4.54	11.03	1.61	12.38	-	-
28.	L_4 x T_3	28.95**	10.85	23.39	11.99	6.46	10.34
29.	L_5 x T_3	38.89**	11.33	38.57**	13.06	9.76	10.34
30.	L_6 x T_3	28.06**	10.02	14.51	10.34	14.51	10.34
31.	L_7 x T_3	30.51**	10.71	23.45*	11.70	9.15	10.34
32.	L_8 x T_3	33.72**	12.12	25.29	13.12	-	-
33.	L_9 x T_3	42.93**	11.07	39.41**	12.47	15.61	10.34
34.	L_{10}x T3	21.19*	10.07	8.87	10.45	7.74	10.34
35.	L_{11} x T3	38.64**	11.24	37.17**	12.84	10.49	10.34
36.	L_{12}x T3	6.15	10.38	-	-	-	-

*,** Significant at 5% and 1%, respectively.

Table 4.3.4 Extent of heterosis, heterobeltiosis and economic heterosis for haulm yield per plant

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	L_1 x T_1	-14.29*	7.05	-	-	-	-
2.	L_2 x T_1	-15.12	7.98	-	-	-	-
3.	L_3 x T_1	5.62	7.73	-	-	-	-
4.	L_4 x T_1	-8.82	6.03	-	-	-	-
5.	L_5 x T_1	15.05*	7.09	11.87	7.96	-	-
6.	L_6 x T_1	0.67	7.32	0.35	8.43	-	-
7.	L_7 x T_1	-16.08*	7.66	-	-	-	-
8.	L_8 x T_1	-5.87	7.69	-	-	-	-
9.	L_9 x T_1	29.25**	7.42	27.16**	8.43	-	-
10.	L_{10}x T1	-1.00	7.78	-	-	-	-
11.	L_{11} x T1	-2.69	7.31	-	-	-	-
12.	L_{12}x T1	5.63	7.03	1.80	7.82	-	-
13.	L_1 x T_2	-13.23	7.56	-	-	-	-
14.	L_2 x T_2	-12.40	8.63	-	-	-	-
15.	L_3 x T_2	31.80**	8.34	29.61**	9.47	-	-
16.	L_4 x T_2	10.84	6.40	-	-	-	-
17.	L_5 x T_2	31.70**	7.61	19.37*	7.96	-	-
18.	L_6 x T_2	5.28	7.88	-	-	-	-
19.	L_7 x T_2	-16.41*	8.27	-	-	-	-
20.	L_8 x T_2	2.64	8.30	0.42	9.37	-	-
21.	L_9 x T_2	22.15**	7.99	15.36	8.71	-	-
22.	L_{10}x T2	-14.34	8.40	-	-	-	-
23.	L_{11} x T2	6.08	7.86	-	-	-	-
24.	L_{12}x T2	1.51	7.53	-	-	-	-
25.	L_1 x T_3	10.01	7.25	3.49	7.88	-	-
26.	L_2 x T_3	-11.80	8.23	-	-	-	-
27.	L_3 x T_3	26.86**	7.97	23.27*	8.94	-	-
28.	L_4 x T_3	8.38	6.18	-	-	-	-
29.	L_5 x T_3	20.06**	7.29	13.52	7.96	-	-
30.	L_6 x T_3	18.02*	7.54	15.03	8.48	-	-
31.	L_7 x T_3	-3.29	7.90	-	-	-	-
32.	L_8 x T_3	17.02*	7.92	14.29	8.94	-	-
33.	L_9 x T_3	10.46	7.64	9.06	8.71	-	-
34.	L_{10}x T3	-12.01	8.02	-	-	-	-
35.	L_{11} x T3	6.12	7.52	3.23	8.45	-	-
36.	L_{12}x T3	-3.92	7.22	-	-	-	-

*,** Significant at 5% and 1%, respectively.

Table 4.3.5 Extent of heterosis, heterobeltiosis and economic heterosis for barren pegs per plant

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	L_1 x T_1	16.92	12.79	-	-	-	-
2.	L_2 x T_1	14.92	14.12	-	-	-	-
3.	L_3 x T_1	75.76**	20.11	-	-	-	-
4.	L_4 x T_1	20.33	11.26	-	-	-	-
5.	L_5 x T_1	-0.45	8.37	-	-	-	-
6.	L_6 x T_1	27.40	14.21	-	-	-	-
7.	L_7 x T_1	36.33	20.66	-	-	-	-
8.	L_8 x T_1	13.24	21.95	-	-	-	-
9.	L_9 x T_1	20.79	11.82	-	-	-	-
10.	L_{10}x T1	70.85**	15.43	-	-	-	-
11.	L_{11} x T1	-1.65	10.98	-	-	-	-
12.	L_{12}x T1	25.12	13.90	-	-	-	-
13.	L_1 x T2	29.76*	14.56	-	-	-	-
14.	L_2 x T_2	29.54	16.32	-	-	-	-
15.	L_3 x T_2	53.08*	24.88	-	-	-	-
16.	L_4 x T_2	114.71**	12.62	-	-	-	-
17.	L_5 x T_2	73.54**	9.10	-	-	-	-
18.	L_6 x T_2	-4.10	16.45	-	-	-	-
19.	L_7 x T_2	137.93**	25.74	-	-	-	-
20.	L_8 x T_2	50.70	27.77	-	-	-	-
21.	L_9 x T_2	43.57**	13.33	-	-	-	-
22.	L_{10}x T2	47.27*	18.10	-	-	-	-
23.	L_{11} x T2	74.95**	12.26	-	-	-	-
24.	L_{12}x T2	10.60	16.03	-	-	-	-
25.	L_1 x T_3	-11.95	9.59	-9.39	11.40	-	-
26.	L_2 x T_3	-33.18**	10.33	-29.97*	12.50	-	-
27.	L_3 x T_3	54.16**	13.20	-	-	-	-
28.	L_4 x T_3	-0.82	8.71	-	-	-	-
29.	L_5 x T_3	-24.20**	6.87	-	-	-	-
30.	L_6 x T_3	-9.75	10.38	-4.91	12.62	-	-
31.	L_7 x T_3	-28.40*	13.44	-	-	-	-
32.	L_8 x T_3	44.13**	13.97	-	-	-	-
33.	L_9 x T_3	-29.50**	9.04	-23.02*	11.40	-	-
34.	L_{10}x T3	-2.29	11.01	-	-	-	-
35.	L_{11} x T3	-2.14	8.54	-	-	-	-
36.	L_{12}x T3	-18.96	10.21	-16.11	12.20	-	-

*,** Significant at 5% and 1%, respectively.

4.3.6 Total pods per plant (Table 4.3.6) :

Ten hybrids exhibited significant positive heterosis ranging from 8.62 per cent (L_7 x T_1) to 44.89 per cent (L_{10} x T_1) and negative heterosis in 4 hybrids ranging from –9.11 per cent (L_3 x T_3) to –13.19 per cent (L_4 x T_3).

Six hybrids exhibited significant heterobeltiosis. Highest estimates of heterobeltiosis was exhibited by hybrid L_{10} x T_1 (32.91 %) followed by L_6 x T_3 (29.86 %), L_{12} x T_1 (29.79 %), L_1 x T_2 (21.97 %), L_1 x T_3 (21.07 %) and L_1 x T_1 (17.42). All these hybrids also exhibited economic heterosis except hybrid L_1 x T_1. Economic heterosis in these hybrids ranged from 8.95 to 22.63 per cent.

4.3.7 Mature pods per plant (Table 4.3.7) :

Twelve hybrids exhibited significant positive heterosis. Heterosis in these hybrids ranged from 10.15 per cent (L_3 x T_1) to 31.83 per cent (L_{10} x T_1). Two hybrids viz., L_{11} x T_2 (–16.20%) and L_6 x T_1 (–16.12%) also exhibited significant negative heterosis for this trait.

Heterobeltiosis was significant in 7 hybrids. The highest heterobeltiosis was observed in hybrid L_{10} x T_1 (29.89 %) followed by L_{12} x T_1 (28.60 %), L_1 x T_2 (20.81 %), L_1 x T_1 (16.91 %), L_6 x T_3 (16.35 %), L_1 x T_3 (13.58 %) and L_7 x T_1 (12.60 %). Out of above seven hybrids, four hybrids viz., L_{10} x T_1, L_1 x T_2, L_1 x T_1 and L_{12} x T_1 were also exhibited economic heterosis with a magnitude of 16.28, 15.95, 12.21 and 11.83 per cent, respectively.

4.3.8 Pod yield per plant (Table 4.3.8) :

Significant positive heterosis was observed in 19 crosses ranging from 11.33 per cent (L_3 x T_3) to 46.85 per cent (L_{12} x T_1). Heterosis in negative

Table 4.3.6 **Extent of heterosis, heterobeltiosis and economic heterosis for total pods per plant**

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	L_1 x T_1	30.51**	4.50	17.42**	4.67	8.34	4.31
2.	L_2 x T_1	4.51	4.63	-	-	-	-
3.	L_3 x T_1	4.09	4.19	0.53	4.67	-	-
4.	L_4 x T_1	8.14	4.30	1.87	4.67	-	-
5.	L_5 x T_1	8.37	4.22	3.86	4.67	-	-
6.	L_6 x T_1	-11.81**	4.01	-	-	-	-
7.	L_7 x T_1	8.62*	4.08	7.72	4.67	-	-
8.	L_8 x T_1	9.60*	4.19	5.73	4.67	-	-
9.	L_9 x T_1	2.14	4.44	-	-	-	-
10.	L_{10}x T1	44.89**	4.41	32.91**	4.67	22.63**	4.31
11.	L_{11} x T1	7.93	4.47	-	-	-	-
12.	L_{12}x T1	34.54**	4.19	29.79**	4.67	19.76**	4.31
13.	L_1 x T2	40.40**	4.30	21.97**	4.31	21.97**	4.31
14.	L_2 x T_2	-2.68	4.42	-	-	-	-
15.	L_3 x T_2	4.22	4.02	-	-	-	-
16.	L_4 x T_2	-0.58	4.11	-	-	-	-
17.	L_5 x T_2	-5.79	4.05	-	-	-	-
18.	L_6 x T_2	-3.90	3.85	-	-	-	-
19.	L_7 x T_2	-0.05	3.92	-	-	-	-
20.	L_8 x T_2	0.41	4.02	-	-	-	-
21.	L_9 x T_2	-3.52	4.24	-	-	-	-
22.	L_{10}x T2	-11.94**	4.22	-	-	-	-
23.	L_{11} x T2	-6.98	4.27	-	-	-	-
24.	L_{12}x T2	0.90	4.02	-	-	-	-
25.	L_1 x T_3	33.08**	4.56	21.07**	4.79	8.95*	4.31
26.	L_2 x T_3	1.13	4.70	-	-	-	-
27.	L_3 x T_3	-9.11*	4.24	-	-	-	-
28.	L_4 x T_3	-13.19**	4.35	-	-	-	-
29.	L_5 x T_3	11.94**	4.28	8.58	4.79	-	-
30.	L_6 x T_3	32.74**	4.06	29.86**	4.58	22.17**	4.31
31.	L_7 x T_3	-12.55**	4.13	-	-	-	-
32.	L_8 x T_3	5.46	4.25	2.98	4.79	-	-
33.	L_9 x T_3	8.55	4.50	0.17	4.79	-	-
34.	L_{10}x T3	10.96*	4.47	2.96	4.79	-	-
35.	L_{11} x T3	2.18	4.53	-	-	-	-
36.	L_{12}x T3	1.09	4.25	-	-	-	-

*,** Significant at 5% and 1%, respectively.

Table 4.3.7 **Extent of heterosis, heterobeltiosis and economic heterosis for mature pods per plant**

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	$L_1 \times T_1$	22.67**	5.03	16.91**	5.53	12.21*	5.31
2.	$L_2 \times T_1$	10.23	5.88	-	-	-	-
3.	$L_3 \times T_1$	10.15*	4.95	3.51	5.37	2.36	5.31
4.	$L_4 \times T_1$	1.97	5.28	1.78	6.08	-	-
5.	$L_5 \times T_1$	-7.68	6.02	-	-	-	-
6.	$L_6 \times T_1$	-16.12**	5.24	-	-	-	-
7.	$L_7 \times T_1$	15.64**	5.43	12.60*	6.11	-	-
8.	$L_8 \times T_1$	13.50**	4.92	6.10	5.31	6.10	5.31
9.	$L_9 \times T_1$	15.33**	5.57	9.44	6.11	-	-
10.	$L_{10} \times T_1$	31.83**	5.21	29.89**	5.93	16.38**	5.31
11.	$L_{11} \times T_1$	4.96	5.54	0.19	6.11	-	-
12.	$L_{12} \times T_1$	28.96**	5.30	28.60**	6.11	11.83*	5.31
13.	$L_1 \times T_2$	24.40**	4.93	20.81**	5.53	15.95**	5.31
14.	$L_2 \times T_2$	9.41	5.75	-	-	-	-
15.	$L_3 \times T_2$	5.13	4.86	0.63	5.37	-	-
16.	$L_4 \times T_2$	-6.95	5.17	-	-	-	-
17.	$L_5 \times T_2$	3.65	5.89	-	-	-	-
18.	$L_6 \times T_2$	1.92	5.14	0.77	5.87	-	-
19.	$L_7 \times T_2$	-10.05	5.32	-	-	-	-
20.	$L_8 \times T_2$	-3.03	4.83	-	-	-	-
21.	$L_9 \times T_2$	-0.44	5.46	-	-	-	-
22.	$L_{10} \times T_2$	-4.87	5.11	-	-	-	-
23.	$L_{11} \times T_2$	-16.20**	5.43	-	-	-	-
24.	$L_{12} \times T_2$	1.36	5.20	-	-	-	-
25.	$L_1 \times T_3$	25.30**	5.28	13.58*	5.53	9.02	5.31
26.	$L_2 \times T_3$	12.21	6.23	6.11	6.80	-	-
27.	$L_3 \times T_3$	-5.64	5.20	-	-	-	-
28.	$L_4 \times T_3$	2.68	5.56	-	-	-	-
29.	$L_5 \times T_3$	12.73*	6.40	3.80	6.80	-	-
30.	$L_6 \times T_3$	23.59**	5.53	16.35**	6.01	2.83	5.31
31.	$L_7 \times T_3$	-8.32	5.73	-	-	-	-
32.	$L_8 \times T_3$	12.96*	5.17	0.55	5.31	0.55	5.31
33.	$L_9 \times T_3$	3.80	5.89	3.77	6.80	-	-
34.	$L_{10} \times T_3$	8.26	5.49	1.27	5.93	-	-
35.	$L_{11} \times T_3$	-5.32	5.85	-	-	-	-
36.	$L_{12} \times T_3$	8.96	5.59	3.64	6.14	-	-

*,** Significant at 5% and 1%, respectively.

Table 4.3.8 **Extent of heterosis, heterobeltiosis and economic heterosis for pod yield per plant**

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	$L_1 \times T_1$	11.35	6.12	6.02	6.73	-	-
2.	$L_2 \times T_1$	15.12*	7.32	1.46	7.44	-	-
3.	$L_3 \times T_1$	16.59**	5.65	3.74	5.80	3.74	5.80
4.	$L_4 \times T_1$	20.79**	6.81	14.35	7.44	-	-
5.	$L_5 \times T_1$	5.99	6.95	-	-	-	-
6.	$L_6 \times T_1$	7.03	6.19	2.88	6.87	-	-
7.	$L_7 \times T_1$	12.89*	6.48	12.31	7.44	-	-
8.	$L_8 \times T_1$	12.98	6.60	10.40	7.44	-	-
9.	$L_9 \times T_1$	16.15**	6.15	10.98	6.78	-	-
10.	$L_{10} \times T_1$	39.26**	5.87	27.88**	6.23	19.17**	5.80
11.	$L_{11} \times T_1$	9.86	7.37	-	-	-	-
12.	$L_{12} \times T_1$	46.85**	5.97	36.77**	6.42	23.58**	5.80
13.	$L_1 \times T_2$	28.86**	6.03	24.62**	6.73	7.46	5.80
14.	$L_2 \times T_2$	3.03	7.18	-	-	-	-
15.	$L_3 \times T_2$	14.00*	5.57	2.92	5.80	2.92	5.80
16.	$L_4 \times T_2$	-15.18*	6.69	-	-	-	-
17.	$L_5 \times T_2$	18.94**	6.83	8.71	7.20	-	-
18.	$L_6 \times T_2$	25.18**	6.09	22.24**	6.87	3.32	5.80
19.	$L_7 \times T_2$	8.90	6.37	6.60	7.20	-	-
20.	$L_8 \times T_2$	10.25	6.49	6.04	7.20	-	-
21.	$L_9 \times T_2$	15.38*	6.05	11.99	6.78	-	-
22.	$L_{10} \times T_2$	15.19**	5.79	7.37	6.23	0.06	5.80
23.	$L_{11} \times T_2$	-5.36	7.23	-	-	-	-
24.	$L_{12} \times T_2$	20.44**	5.88	13.90*	6.42	2.92	5.80
25.	$L_1 \times T_3$	22.57**	6.09	17.29*	6.73	1.13	5.80
26.	$L_2 \times T_3$	-16.98*	7.27	-	-	-	-
27.	$L_3 \times T_3$	11.33*	5.62	-	-	-	-
28.	$L_4 \times T_3$	-3.05	6.77	-	-	-	-
29.	$L_5 \times T_3$	9.06	6.91	0.68	7.36	-	-
30.	$L_6 \times T_3$	35.26**	6.15	30.68**	6.87	10.45	5.80
31.	$L_7 \times T_3$	-9.52	6.45	-	-	-	-
32.	$L_8 \times T_3$	27.38**	6.56	23.82**	7.36	-	-
33.	$L_9 \times T_3$	6.01	6.12	1.82	6.78	-	-
34.	$L_{10} \times T_3$	6.58	5.84	-	-	-	-
35.	$L_{11} \times T_3$	-9.11	7.32	-	-	-	-
36.	$L_{12} \times T_3$	18.65**	5.94	11.07	6.42	0.36	5.80

*,** Significant at 5% and 1%, respectively.

direction was significant in two hybrids viz., L_2 x T_3 (–16.98%) and L_4 x T_2 (–15.18 %).

Heterobeltiosis for higher pod yield per plant was observed in eight hybrids viz., L_{12} x T_1 (36.77 %), L_6 x T_3 (30.68 %), L_{10} x T_1 (27.88%), L_1 x T_2 (24.62 %), L_8 x T_3 (23.82 %), L_6 x T_2 (22.24 %), L_1 x T_3 (17.29 %) and L_{12} x T_2 (13.90 %). Out of these, two hybrids viz., L_{12} x T_1 (23.58 %) and L_{10} x T_1 (19.17 %) also exhibited economic heterosis for pod yield per plant.

4.3.9 Kernel yield per plant (Table 4.3.9) :

Significant positive heterosis was observed in 16 hybrids with a range from 18.62 per cent (L_3 x T_1) to 50.39 per cent (L_6 x T_3). Heterosis in negative direction was significant in only one cross i.e. L_4 x T_2 (–16.62%).

Significant heterobeltiosis was recorded in 7 crosses with a range from 25.67 (L_6 x T_2) to 44.05 per cent (L_8 x T_3). Out of these four hybrids viz., L_{12} x T_1 (37.22 %), L_{10} x T_1 (32.37%), L_6 x T_3 (23.01 %) and L_1 x T_2 (16.84 %) manifested significant economic heterosis.

4.3.10 Harvest index (Table 4.3.10) :

Heterosis in positives directions was significant is ten crosses. Heterosis in these crosses ranged from 12.27 per cent (L_{12} x T_1) to 23.36 per cent (L_1 x T_2). One hybrid L_4 x T_2 (–18.08 %) exhibited significant negative heterosis for harvest index.

The significant heterobeltiosis was recorded in six hybrids having the magnitude from 12.67 per cent (L_7 x T_2) to 18.51 per cent (L_1 x T_2). None of the hybrids exhibited significant economic heterosis.

Table 4.3.9 **Extent of heterosis, heterobeltiosis and economic heterosis for kernel yield per plant**

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	L_1 x T_1	13.45	7.47	11.09	8.44	-	-
2.	L_2 x T_1	19.38*	9.12	-	-	-	-
3.	L_3 x T_1	18.62**	6.95	9.00	7.38	8.50	7.35
4.	L_4 x T_1	14.07	8.20	6.08	8.81	-	-
5.	L_5 x T_1	3.31	8.26	-	-	-	-
6.	L_6 x T_1	5.16	7.48	3.15	8.47	-	-
7.	L_7 x T_1	10.89	7.67	10.32	8.81	-	-
8.	L_8 x T_1	12.87	8.00	7.68	8.81	-	-
9.	L_9 x T_1	11.99	7.13	5.07	7.72	-	-
10.	L_{10}x T_1	46.51**	7.04	36.05**	7.55	32.37**	7.35
11.	L_{11} x T_1	7.17	9.10	-	-	-	-
12.	L_{12}x T_1	49.64**	6.94	37.22**	7.35	37.22**	7.35
13.	L_1 x T_2	36.93**	7.46	34.27**	8.44	16.84*	7.35
14.	L_2 x T_2	8.70	9.11	-	-	-	-
15.	L_3 x T_2	17.79*	6.95	8.38	7.38	7.88	7.35
16.	L_4 x T_2	-16.62*	8.19	-	-	-	-
17.	L_5 x T_2	23.18**	8.25	13.56	8.78	-	-
18.	L_6 x T_2	27.93**	7.47	25.67**	8.47	8.96	7.35
19.	L_7 x T_2	9.31	7.66	8.59	8.78	-	-
20.	L_8 x T_2	20.44*	7.98	14.75	8.78	-	-
21.	L_9 x T_2	12.07	7.12	5.30	7.72	0.19	7.35
22.	L_{10}x T_2	22.72**	7.03	14.11	7.55	11.02	7.35
23.	L_{11} x T_2	-4.58	9.08	-	-	-	-
24.	L_{12}x T_2	23.36**	6.93	13.27	7.35	13.27	7.35
25.	L_1 x T_3	37.24**	7.76	29.24**	8.44	12.47	7.35
26.	L_2 x T_3	-3.05	9.57	-	-	-	-
27.	L_3 x T_3	21.51**	7.21	7.68	7.38	7.19	7.35
28.	L_4 x T_3	0.78	8.56	-	-	-	-
29.	L_5 x T_3	11.58	8.63	7.01	9.55	-	-
30.	L_6 x T_3	50.39**	7.78	41.88**	8.47	23.01**	7.35
31.	L_7 x T_3	-5.50	7.98	-	-	-	-
32.	L_8 x T_3	45.14**	8.34	44.05**	9.55	10.75	7.35
33.	L_9 x T_3	6.66	7.40	-	-	-	-
34.	L_{10}x T_3	11.87	7.30	0.14	7.55	-	-
35.	L_{11} x T_3	-3.52	9.54	-	-	-	-
36.	L_{12}x T_3	26.20**	7.19	11.61	7.35	11.61	7.35

*,** Significant at 5% and 1%, respectively.

Table 4.3.10 **Extent of heterosis, heterobeltiosis and economic heterosis for harvest index**

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	$L_1 \times T_1$	15.93**	6.05	14.59*	6.90	-	-
2.	$L_2 \times T_1$	20.20**	6.27	17.30*	7.07	-	-
3.	$L_3 \times T_1$	5.72	5.49	-	-	-	-
4.	$L_4 \times T_1$	18.10*	7.04	2.73	7.07	-	-
5.	$L_5 \times T_1$	-5.35	6.53	-	-	-	-
6.	$L_6 \times T_1$	3.93	5.96	1.30	6.71	-	-
7.	$L_7 \times T_1$	18.41**	5.96	15.43*	6.71	-	-
8.	$L_8 \times T_1$	11.65	6.00	9.50	6.80	-	-
9.	$L_9 \times T_1$	-6.04	5.89	-	-	-	-
10.	$L_{10} \times T_1$	19.58**	5.59	10.00	5.94	6.66	5.75
11.	$L_{11} \times T_1$	8.23	6.67	-	-	-	-
12.	$L_{12} \times T_1$	12.27*	5.99	9.88	6.77	-	-
13.	$L_1 \times T_2$	23.36**	5.73	18.51**	6.36	7.22	5.75
14.	$L_2 \times T_2$	10.89	5.93	2.95	6.36	-	-
15.	$L_3 \times T_2$	-7.43	5.23	-	-	-	-
16.	$L_4 \times T_2$	-18.08**	6.61	-	-	-	-
17.	$L_5 \times T_2$	-6.22	6.17	-	-	-	-
18.	$L_6 \times T_2$	10.07	5.66	7.21	6.36	-	-
19.	$L_7 \times T_2$	15.69**	5.66	12.67*	6.36	1.94	5.75
20.	$L_8 \times T_2$	4.46	5.69	1.12	6.36	-	-
21.	$L_9 \times T_2$	-2.50	5.59	-	-	-	-
22.	$L_{10} \times T_2$	16.76**	5.32	12.85*	5.94	9.42	5.75
23.	$L_{11} \times T_2$	-8.02	6.29	-	-	-	-
24.	$L_{12} \times T_2$	9.91	5.68	6.62	6.36	-	-
25.	$L_1 \times T_3$	6.16	5.92	5.04	6.76	-	-
26.	$L_2 \times T_3$	-3.54	6.13	-	-	-	-
27.	$L_3 \times T_3$	-7.06	5.38	-	-	-	-
28.	$L_4 \times T_3$	-9.10	6.86	-	-	-	-
29.	$L_5 \times T_3$	-4.68	6.38	-	-	-	-
30.	$L_6 \times T_3$	8.00	5.83	7.62	6.71	-	-
31.	$L_7 \times T_3$	-4.28	5.83	-	-	-	-
32.	$L_8 \times T_3$	4.61	5.87	4.32	6.76	-	-
33.	$L_9 \times T_3$	-2.26	5.76	-	-	-	-
34.	$L_{10} \times T_3$	10.71	5.47	3.96	5.94	0.81	5.75
35.	$L_{11} \times T_3$	-9.78	6.51	-	-	-	-
36.	$L_{12} \times T_3$	12.48*	5.86	12.41	6.76	-	-

*,** Significant at 5% and 1%, respectively.

4.3.11 Shelling per cent (Table 4.3.11) :

Significant positive heterosis was observed in 12 crosses. Heterosis in these crosses ranged from 5.13 per cent (L_{10} x T_1) to 16.49 per cent (L_2 x T_3). One hybrid viz., L_4 x T_1 (–5.52 %) exhibited negative heterosis for this trait.

Heterobeltiosis was significant in 7 crosses ranging from 6.51 per cent (L_{10} x T_2) to 14.08 per cent (L_2 x T_3). None of the hybrid exhibited economic heterosis.

4.3.12 100–kernel weight (Table 4.3.12) :

For 100–kernel weight 9 hybrids exhibited significant positive heterosis with the range from 7.13 per cent (L_6 x T_2) to 23.40 per cent (L_{12} x T_3). Negative heterosis recorded in five hybrids ranging from – 6.23 per cent (L_4 x T_2) to –22.37 per cent (L_{11} x T_2).

The significant heterobeltiosis was observed in five hybrids with the range from 6.95 per cent (L_3 x T_3) to 12.31 per cent (L_{12} x T_3). None of the hybrids exhibited economic heterosis.

4.3.13 Oil content (Table 4.3.13) :

Heterosis for oil content was positive significant in 17 hybrids. Heterosis in these crosses ranged from 3.13 per cent (L_{12} x T_2) to 11.09 per cent (L_7 x T_3). Heterosis in negative direction were observed in 8 crosses ranging from –3.18 per cent (L_2 x T_3) to –8.25 per cent (L_{11} x T_1). Heterobeltiosis was significant in 7 hybrids varied from 3.63 per cent (L_2 x T_2) to 9.00 per cent (L_1 x T_3).

The estimates of economic heterosis was significant in two hybrids viz., L_1 x T_3 (3.25 %) and L_5 x T_2 (4.19 %).

Table 4.3.11 Extent of heterosis, heterobeltiosis and economic heterosis for shelling percent

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	$L_1 \times T_1$	1.67	2.51	-	-	-	-
2.	$L_2 \times T_1$	4.56	2.59	-	-	-	-
3.	$L_3 \times T_1$	1.26	2.53	-	-	-	-
4.	$L_4 \times T_1$	-5.52*	2.49	-	-	-	-
5.	$L_5 \times T_1$	-2.37	2.46	-	-	-	-
6.	$L_6 \times T_1$	-1.81	2.49	-	-	-	-
7.	$L_7 \times T_1$	-2.92	2.41	-	-	-	-
8.	$L_8 \times T_1$	-0.13	2.50	-	-	-	-
9.	$L_9 \times T_1$	-2.72	2.41	-	-	-	-
10.	$L_{10} \times T_1$	5.13*	2.47	3.75	2.82	-	-
11.	$L_{11} \times T_1$	-1.73	2.57	-	-	-	-
12.	$L_{12} \times T_1$	2.72	2.40	1.08	2.73	-	-
13.	$L_1 \times T_2$	5.93*	2.54	4.21	2.89	-	-
14.	$L_2 \times T_2$	6.06*	2.63	0.92	2.89	-	-
15.	$L_3 \times T_2$	2.83	2.56	0.45	2.89	-	-
16.	$L_4 \times T_2$	-2.25	2.52	-	-	-	-
17.	$L_5 \times T_2$	3.30	2.49	2.68	2.86	-	-
18.	$L_6 \times T_2$	1.85	2.52	1.06	2.89	-	-
19.	$L_7 \times T_2$	-1.02	2.44	-	-	-	-
20.	$L_8 \times T_2$	8.78**	2.53	7.47*	2.89	-	-
21.	$L_9 \times T_2$	-2.20	2.44	-	-	-	-
22.	$L_{10} \times T_2$	6.56*	2.50	6.51*	2.89	-	-
23.	$L_{11} \times T_2$	1.01	2.60	-	-	-	-
24.	$L_{12} \times T_2$	2.43	2.43	-	-	-	-
25.	$L_1 \times T_3$	11.61**	2.62	10.14**	2.99	-	-
26.	$L_2 \times T_3$	16.49**	2.71	14.08**	3.07	-	-
27.	$L_3 \times T_3$	8.88**	2.64	8.21**	3.03	-	-
28.	$L_4 \times T_3$	2.98	2.59	0.59	2.93	-	-
29.	$L_5 \times T_3$	1.97	2.56	-	-	-	-
30.	$L_6 \times T_3$	11.04**	2.60	8.65**	2.94	-	-
31.	$L_7 \times T_3$	3.01	2.51	-	-	-	-
32.	$L_8 \times T_3$	13.30**	2.61	11.34**	2.96	-	-
33.	$L_9 \times T_3$	1.17	2.51	-	-	-	-
34.	$L_{10} \times T_3$	4.85	2.58	1.86	2.89	-	-
35.	$L_{11} \times T_3$	6.33*	2.68	5.25	3.07	-	-
36.	$L_{12} \times T_3$	6.10*	2.50	0.19	2.73	-	-

*,** Significant at 5% and 1%, respectively.

Table 4.3.12 Extent of heterosis, heterobeltiosis and economic heterosis for 100-kernel weight

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	$L_1 \times T_1$	0.11	2.86	-	-	-	-
2.	$L_2 \times T_1$	1.26	3.03	-	-	-	-
3.	$L_3 \times T_1$	-1.45	2.72	-	-	-	-
4.	$L_4 \times T_1$	4.60	2.89	0.07	3.19	-	-
5.	$L_5 \times T_1$	9.48**	2.72	7.98*	3.10	-	-
6.	$L_6 \times T_1$	-4.74	2.79	-	-	-	-
7.	$L_7 \times T_1$	2.22	2.68	-	-	-	-
8.	$L_8 \times T_1$	1.64	2.92	-	-	-	-
9.	$L_9 \times T_1$	3.92	2.43	-	-	-	-
10.	$L_{10} \times T_1$	5.15	2.61	-	-	-	-
11.	$L_{11} \times T_1$	-4.24	3.23	-	-	-	-
12.	$L_{12} \times T_1$	7.61**	2.64	3.23	2.93	-	-
13.	$L_1 \times T_2$	0.92	2.84	-	-	-	-
14.	$L_2 \times T_2$	-7.76*	3.01	-	-	-	-
15.	$L_3 \times T_2$	2.51	2.70	1.65	3.09	-	-
16.	$L_4 \times T_2$	-6.23*	2.87	-	-	-	-
17.	$L_5 \times T_2$	2.69	2.70	1.97	3.10	-	-
18.	$L_6 \times T_2$	7.13*	2.77	5.33	3.14	-	-
19.	$L_7 \times T_2$	-0.82	2.66	-	-	-	-
20.	$L_8 \times T_2$	0.18	2.90	-	-	-	-
21.	$L_9 \times T_2$	-2.42	2.41	-	-	-	-
22.	$L_{10} \times T_2$	9.59**	2.59	4.50	2.85	-	-
23.	$L_{11} \times T_2$	-22.37**	3.21	-	-	-	-
24.	$L_{12} \times T_2$	3.40	2.63	-	-	-	-
25.	$L_1 \times T_3$	-2.05	3.02	-	-	-	-
26.	$L_2 \times T_3$	4.20	3.22	-	-	-	-
27.	$L_3 \times T_3$	14.64**	2.87	6.95*	3.09	-	-
28.	$L_4 \times T_3$	-7.72*	3.06	-	-	-	-
29.	$L_5 \times T_3$	12.92**	2.87	5.48	3.10	-	-
30.	$L_6 \times T_3$	15.37**	2.95	10.26**	3.25	-	-
31.	$L_7 \times T_3$	1.50	2.83	-	-	-	-
32.	$L_8 \times T_3$	4.81	3.10	4.56	3.57	-	-
33.	$L_9 \times T_3$	0.98	2.55	-	-	-	-
34.	$L_{10} \times T_3$	23.36**	2.75	10.96**	2.85	-	-
35.	$L_{11} \times T_3$	-20.25**	3.45	-	-	-	-
36.	$L_{12} \times T_3$	23.40**	2.79	12.31**	2.93	-	-

*,** Significant at 5% and 1%, respectively.

Table 4.3.13 Extent of heterosis, heterobeltiosis and economic heterosis for oil content

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	$L_1 \times T_1$	-4.52**	1.44	-	-	-	-
2.	$L_2 \times T_1$	-6.22**	1.45	-	-	-	-
3.	$L_3 \times T_1$	3.87**	1.46	-	-	-	-
4.	$L_4 \times T_1$	-1.75	1.44	-	-	-	-
5.	$L_5 \times T_1$	-7.98**	1.39	-	-	-	-
6.	$L_6 \times T_1$	6.02**	1.45	3.03	1.63	0.61	1.59
7.	$L_7 \times T_1$	7.52**	1.48	2.27	1.63	-	-
8.	$L_8 \times T_1$	2.09	1.45	-	-	-	-
9.	$L_9 \times T_1$	5.02**	1.46	1.61	1.63	-	-
10.	$L_{10} \times T_1$	-5.40**	1.42	-	-	-	-
11.	$L_{11} \times T_1$	-8.25**	1.43	-	-	-	-
12.	$L_{12} \times T_1$	2.15	1.42	1.09	1.63	-	-
13.	$L_1 \times T_2$	2.09	1.45	0.28	1.65	-	-
14.	$L_2 \times T_2$	6.28**	1.46	3.63*	1.65	-	-
15.	$L_3 \times T_2$	-1.60	1.47	-	-	-	-
16.	$L_4 \times T_2$	3.82**	1.45	1.87	1.65	-	-
17.	$L_5 \times T_2$	6.06**	1.40	4.19**	1.59	4.19**	1.59
18.	$L_6 \times T_2$	5.35**	1.46	2.99	1.65	-	-
19.	$L_7 \times T_2$	4.29**	1.49	-	-	-	-
20.	$L_8 \times T_2$	2.61	1.46	0.20	1.65	-	-
21.	$L_9 \times T_2$	-2.24	1.46	-	-	-	-
22.	$L_{10} \times T_2$	-6.72**	1.42	-	-	-	-
23.	$L_{11} \times T_2$	-0.84	1.44	-	-	-	-
24.	$L_{12} \times T_2$	3.13*	1.43	2.66	1.65	-	-
25.	$L_1 \times T_3$	9.96**	1.46	9.00**	1.68	3.25*	1.59
26.	$L_2 \times T_3$	-3.18*	1.48	-	-	-	-
27.	$L_3 \times T_3$	8.25**	1.49	5.68**	1.68	0.10	1.59
28.	$L_4 \times T_3$	7.11**	1.47	6.05**	1.68	0.46	1.59
29.	$L_5 \times T_3$	4.12**	1.41	1.38	1.59	1.38	1.59
30.	$L_6 \times T_3$	0.52	1.47	-	-	-	-
31.	$L_7 \times T_3$	11.09**	1.50	7.21**	1.68	1.56	1.59
32.	$L_8 \times T_3$	-1.08	1.47	-	-	-	-
33.	$L_9 \times T_3$	-3.49*	1.48	-	-	-	-
34.	$L_{10} \times T_3$	-1.21	1.44	-	-	-	-
35.	$L_{11} \times T_3$	3.32*	1.45	3.20	1.68	-	-
36.	$L_{12} \times T_3$	4.87**	1.45	4.38**	1.66	-	-

*,** Significant at 5% and 1%, respectively.

4.3.14 Protein content (Table 4.3.14) :

The number of hybrids which manifested significant positive heterosis were 11. Heterosis in these crosses ranged from 4.58 per cent (L_{11} x T_1) to 11.90 per cent (L_5 x T_2). Heterosis in negative direction was significant in 8 hybrids ranging from –5.22 per cent to –14.15 per cent (L_6 x T_2).

The significant heterobeltiosis was recorded in 3 crosses. It was maximum in L_8 x T_1 (8.82 %) followed by L_{10} x T_2 (6.80 %) and L_9 x T_3 (6.57 %). None of these hybrids exhibited significant economic heterosis.

4.3.15 Chlorophyll content (Table 4.3.15) :

Significant heterosis in positive direction was recorded in one hybrid L_6 x T_1 (28.03 %) and negative in two hybrids viz., L_2 x T_2 (–33.97 %) and L_4 x T_2 (–26.87 %). None of the hybrids exhibited significant heterobeltiosis and economic heterosis.

4.4 Combining Ability Analysis

Analysis of variance revealed (Table 4.1) significant difference among crosses for all the characters except chlorophyll content and chlorophyll stability index. Partitioning of this significant variance in lines, testers and lines x testers revealed significant difference among GCA of lines and SCA of hybrids for all the characters. Difference among GCA of testers was also significant for all the characters except height of main axis and kernel yield per plant. The contribution of lines, testers and lines x tester in sum of square of hybrids (Table 4.4.1) revealed that contribution of lines was maximum in all the characters except total pods per plant and oil content where line x tester i.e. SCA was contributing maximum.

Table 4.3.14 Extent of heterosis, heterobeltiosis and economic heterosis for protein content

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	$L_1 \times T_1$	-0.47	1.99	-	-	-	-
2.	$L_2 \times T_1$	1.89	1.88	-	-	-	-
3.	$L_3 \times T_1$	3.08	2.00	0.10	2.24	-	-
4.	$L_4 \times T_1$	5.36**	1.98	3.25	2.24	-	-
5.	$L_5 \times T_1$	-0.55	2.05	-	-	-	-
6.	$L_6 \times T_1$	-2.73	1.84	-	-	-	-
7.	$L_7 \times T_1$	1.97	1.82	-	-	-	-
8.	$L_8 \times T_1$	10.72**	1.91	8.82**	2.17	-	-
9.	$L_9 \times T_1$	7.14**	1.86	2.58	2.05	-	-
10.	$L_{10} \times T_1$	4.61*	1.87	0.52	2.07	-	-
11.	$L_{11} \times T_1$	4.58*	2.03	-	-	-	-
12.	$L_{12} \times T_1$	-7.37**	2.00	-	-	-	-
13.	$L_1 \times T_2$	-1.33	1.91	-	-	-	-
14.	$L_2 \times T_2$	2.21	1.81	1.99	2.08	-	-
15.	$L_3 \times T_2$	-6.49**	1.93	-	-	-	-
16.	$L_4 \times T_2$	3.12	1.91	-	-	-	-
17.	$L_5 \times T_2$	11.90**	1.97	2.32	2.08	-	-
18.	$L_6 \times T_2$	-14.15**	1.77	-	-	-	-
19.	$L_7 \times T_2$	5.63**	1.76	2.86	1.97	2.86	1.97
20.	$L_8 \times T_2$	-2.33	1.84	-	-	-	-
21.	$L_9 \times T_2$	-2.19	1.79	-	-	-	-
22.	$L_{10} \times T_2$	7.16**	1.80	6.80**	2.07	1.89	1.97
23.	$L_{11} \times T_2$	3.23	1.96	-	-	-	-
24.	$L_{12} \times T_2$	-5.22**	1.92	-	-	-	-
25.	$L_1 \times T_3$	-0.97	1.93	-	-	-	-
26.	$L_2 \times T_3$	0.13	1.82	-	-	-	-
27.	$L_3 \times T_3$	-8.88**	1.94	-	-	-	-
28.	$L_4 \times T_3$	6.46**	1.92	1.40	2.12	-	-
29.	$L_5 \times T_3$	8.18**	1.99	-	-	-	-
30.	$L_6 \times T_3$	-7.48**	1.79	-	-	-	-
31.	$L_7 \times T_3$	-13.13**	1.77	-	-	-	-
32.	$L_8 \times T_3$	0.93	1.86	-	-	-	-
33.	$L_9 \times T_3$	8.18**	1.81	6.57**	2.05	2.45	1.97
34.	$L_{10} \times T_3$	1.39	1.81	0.26	2.07	-	-
35.	$L_{11} \times T_3$	3.82	1.97	-	-	-	-
36.	$L_{12} \times T_3$	-5.72**	1.94	-	-	-	-

*,** Significant at 5% and 1%, respectively.

Table 4.3.15 Extent of heterosis, heterobeltiosis and economic heterosis for chlorophyll content

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	L_1 x T_1	14.55	13.62	11.11	15.26	-	-
2.	L_2 x T_1	7.79	12.09	-	-	-	-
3.	L_3 x T_1	1.73	13.95	-	-	-	-
4.	L_4 x T_1	-2.19	12.41	-	-	-	-
5.	L_5 x T_1	18.97	12.58	13.51	13.85	-	-
6.	L_6 x T_1	28.03*	13.21	28.00	15.25	-	-
7.	L_7 x T_1	-4.71	11.29	-	-	-	-
8.	L_8 x T_1	-9.23	14.69	-	-	-	-
9.	L_9 x T_1	-6.11	12.87	-	-	-	-
10.	L_{10}x T_1	1.40	12.39	-	-	-	-
11.	L_{11} x T_1	-11.27	14.09	-	-	-	-
12.	L_{12}x T_1	-0.02	13.05	-	-	-	-
13.	L_1 x T_2	-20.07	11.52	-	-	-	-
14.	L_2 x T_2	-33.97**	10.40	-	-	-	-
15.	L_3 x T_2	-11.42	11.75	-	-	-	-
16.	L_4 x T_2	-26.87*	10.64	-	-	-	-
17.	L_5 x T_2	-7.68	10.76	-	-	-	-
18.	L_6 x T_2	-7.21	11.22	-	-	-	-
19.	L_7 x T_2	-17.95	9.81	-	-	-	-
20.	L_8 x T_2	-23.01	12.27	-	-	-	-
21.	L_9 x T_2	-13.58	10.98	-	-	-	-
22.	L_{10}x T_2	-4.15	10.62	-	-	-	-
23.	L_{11} x T_2	-9.52	11.85	-	-	-	-
24.	L_{12}x T_2	3.25	11.10	-	-	-	-
25.	L_1 x T_3	-12.55	13.79	-	-	-	-
26.	L_2 x T_3	-2.38	12.22	-	-	-	-
27.	L_3 x T_3	-8.39	14.12	-	-	-	-
28.	L_4 x T_3	-10.16	12.55	-	-	-	-
29.	L_5 x T_3	15.21	12.72	8.68	13.85	-	-
30.	L_6 x T_3	-7.04	13.37	-	-	-	-
31.	L_7 x T_3	-6.12	11.41	-	-	-	-
32.	L_8 x T_3	1.49	14.89	-	-	-	-
33.	L_9 x T_3	-4.62	13.02	-	-	-	-
34.	L_{10}x T_3	3.77	12.53	-	-	-	-
35.	L_{11} x T_3	2.66	14.27	-	-	-	-
36.	L_{12}x T_3	-0.78	13.20	-	-	-	-

*,** Significant at 5% and 1%, respectively.

Table 4.3.16 **Extent of heterosis, heterobeltiosis and economic heterosis for chlorophyll stability index**

SN.	Crosses	Heterosis	SE	Heterobeltiosis	SE	Economic heterosis	SE
1.	$L_1 \times T_1$	-55.68	36.59	-	-	-	-
2.	$L_2 \times T_1$	-31.08	73.16	-	-	-	-
3.	$L_3 \times T_1$	7.78	66.56	1.89	72.65	-	-
4.	$L_4 \times T_1$	-46.07	62.00	-	-	-	-
5.	$L_5 \times T_1$	-34.95	50.31	-	-	-	-
6.	$L_6 \times T_1$	-27.32	40.06	-	-	-	-
7.	$L_7 \times T_1$	-74.53	63.39	-	-	-	-
8.	$L_8 \times T_1$	51.86	103.87	3.29	81.58	-	-
9.	$L_9 \times T_1$	-77.83	55.01	-	-	-	-
10.	$L_{10} \times T_1$	101.53	98.69	44.27	81.58	-	-
11.	$L_{11} \times T_1$	-7.73	61.99	-	-	-	-
12.	$L_{12} \times T_1$	-28.29	75.11	-	-	-	-
13.	$L_1 \times T_2$	-61.54	40.05	-	-	-	-
14.	$L_2 \times T_2$	99.53	88.44	71.15	87.59	-	-
15.	$L_3 \times T_2$	51.39	78.97	20.62	72.65	-	-
16.	$L_4 \times T_2$	66.75	72.64	26.82	63.79	-	-
17.	$L_5 \times T_2$	161.99	57.09	79.26	45.10	13.30	28.51
18.	$L_6 \times T_2$	-23.66	44.25	-	-	-	-
19.	$L_7 \times T_2$	-18.31	74.55	-	-	-	-
20.	$L_8 \times T_2$	151.53	137.63	93.76	122.42	-	-
21.	$L_9 \times T_2$	-37.49	63.22	-	-	-	-
22.	$L_{10} \times T_2$	104.46	128.68	68.45	122.42	-	-
23.	$L_{11} \times T_2$	-23.37	72.62	-	-	-	-
24.	$L_{12} \times T_2$	102.87	91.30	78.13	92.57	-	-
25.	$L_1 \times T_3$	-33.83	38.14	-	-	-	-
26.	$L_2 \times T_3$	46.49	79.65	39.51	87.59	-	-
27.	$L_3 \times T_3$	27.46	71.89	11.55	72.65	-	-
28.	$L_4 \times T_3$	-10.72	66.61	-	-	-	-
29.	$L_5 \times T_3$	-16.78	53.29	-	-	-	-
30.	$L_6 \times T_3$	-1.85	41.93	-	-	-	-
31.	$L_7 \times T_3$	17.22	68.21	-	-	-	-
32.	$L_8 \times T_3$	98.43	117.47	41.64	96.82	-	-
33.	$L_9 \times T_3$	-14.72	58.60	-	-	-	-
34.	$L_{10} \times T_3$	96.56	110.89	48.63	96.82	-	-
35.	$L_{11} \times T_3$	41.78	66.59	17.57	63.76	-	-
36.	$L_{12} \times T_3$	-45.69	81.97	-	-	-	-

If lines and testers consider random sample of groundnut and using Kemthrone (1957) model i.e. random effect model (Table 4.4.2), the GCA variance of testers was significant for primary branches per plant, harvest index and shelling percent. The GCA variance of lines was significant for all the characters except total pods per plant and oil content whereas SCA variance was significant for all the characters. Where ever the varience was significant varience due to GCA of lines was higher than GCA of testers and SCA varience for all the characters except barren pegs per plant and protein content where SCA varience was higher. For total pods per plant and oil content only SCA varience was there.

In present investigation as lines and testers were selected on the basis of their superiority, therefore, fixed effect model is applicable. According to fixed effect model (Table 4.4.3) magnitude of GCA effects was higher in lines than testers. The magnitude of GCA of lines was also higher than SCA of hybrids for all the characters except barren pegs per plant, total pods per plant, mature pods per plant, oil content and protein content.

The correlation between *per se* performance of lines and their crosses with tester T_1, T_2 and T_3 (Table 4.4.4) was significant positive for 100–kernel weight, pod yield per plant, kernel yield per plant, harvest index and mature pods per plant. Correlation of lines *per se* and *per se* of hybrids with tester T_1 and T_2 was significant for barren pegs per plant, days to flowering and height of main axis, correlation with the *per se* of hybrids of tester T_2 and T_3 for haulm yield per plant and with *per se* of hybrids of T_1 for protein content. No such correlation was observed in any tester for oil content, shelling per cent and total pods per plant.

The characterwise findings of GCA effects of testers and lines, and SCA effects of crosses were as follows (Table 4.4.5) :

Table 4.4.1 Contribution of testers, lines and line x tester in sum of square of hybrids in different characters of groundnut

	Days to flowering	Height of main axis	Primary branches per plant	Haulm yield per plant	Barren pegs per plant	Total pods per plant	Mature pods per plant	Pod yield per plant	Kernel yield per plant	Harvest index	Shelling percent	100-Kernel weight	Oil content	Protein content
Testers	3.16	0.71	6.76	3.03	1.91	6.01	8.25	3.34	1.09	6.43	11.76	0.50	5.27	1.13
Lines	74.84	73.36	61.27	80.36	56.36	41.86	59.38	74.94	76.36	76.93	61.12	87.30	31.46	64.16
Line x Tester	22.00	25.93	31.96	16.61	41.73	52.14	32.37	21.72	22.55	16.65	27.13	12.20	63.27	34.71

Table 4.4.2 GCA and SCA variances (Random effect model) for different characters in groundnut (Kempthorne, 1957)

	Days to flowering	Height of main axis	Primary branches per plant	Haulm yield per plant	Barren pegs per plant	Total pods per plant	Mature pods per plant	Pod yield per plant	Kernel yield per plant	Harvest index	Shelling percent	100-Kernel weight	Oil content	Protein content
σ^2T GCA	@	@	0.03	@	@	@	@	@	@	2.28	0.69	@	@	@
σ^2L GCA	3.67	3.48	0.26	12.73	3.34	@	4.34	7.21	3.79	23.12	2.57	24.25	@	1.26
σ^2 SCA	1.01	1.88	0.12	2.22	5.23	13.48	4.07	2.95	1.55	4.57	0.54	4.70	4.76	1.28
σ^2SCA/σ^2L GCA	0.28	0.49	0.44	0.17	1.57	-	0.94	0.41	0.41	0.19	0.21	0.19	-	1.01

@ Non-significant mean square when tested according to Model-II

Table 4.4.3 GCA and SCA variances for (Fixed effect model) different characters in groundnut

	Days to flowering	Height of main axis	Primary branches per plant	Haulm yield per plant	Barren pegs per plant	Total pods per plant	Mature pods per plant	Pod yield per plant	Kernel yield per plant	Harvest index	Shelling percent	100-Kernel weight	Oil content	Protein content
$\Sigma T\ GCA^2$	0.35	0.05	0.80	1.11	0.39	2.89	2.15	0.91	0.10	5.31	1.47	0.29	0.72	0.06
$\Sigma L\ GCA^2$	44.12	45.19	3.27	148.25	55.96	81.60	62.75	90.11	47.35	271.09	30.21	284.00	17.34	18.56
ΣSCA^2	22.34	41.44	2.52	48.83	115.15	296.65	89.57	64.98	34.13	100.47	11.81	103.38	104.65	28.10
$\Sigma SCA^2/\ \Sigma L\ GCA^2$	0.50	0.92	0.78	0.33	2.06	3.64	1.43	0.72	0.72	0.37	0.39	0.36	6.03	1.51

Table 4.4.4 Correlation coefficient between *per se* of lines and hybrids with different testers for different characters in groundnut

Tester	Days to flowering	Height of main axis	Primary branches per plant	Haulm yield per plant	Barren pegs per plant	Total pods per plant	Mature pods per plant	Pod yield per plant	Kernel yield per plant	Harvest index	Shelling percent	100-Kernel weight	Oil content	Protein content
T_1	0.72**	0.74**	0.61**	0.47	0.76**	-0.03	0.64*	0.80**	0.81**	0.64*	0.44	0.93**	-0.49	0.76**
T_2	0.78**	0.62*	0.24	0.62*	0.85**	0.14	0.61*	0.86**	0.83**	0.76**	0.30	0.90**	0.35	0.37
T_3	0.57	0.52	0.29	0.70*	0.34	0.25	0.60*	0.80**	0.73**	0.83**	-0.17	0.82**	0.17	0.26

*,** Significant at 5% and 1%, respectively

Table 4.4.5 GCA and SCA effects for different charecters in groundnut

SN	Genotype	Days to flowering	Height of main axis	Primary branches per plant	Haulm yield per plant	Barren pegs per plant	Total pods per plant	Mature pods per plant	Pod yield per plant	Kernel yield per plant	Harvest index	Shelling percent	100-Kernel weight	Oil content	Protein content	Chloro-phyll content	Chlorophyll stability index
1	T_1	0.00	-0.10	-0.19	-0.26	-0.35	1.42**	1.23**	0.71*	0.28	0.99	-0.96*	0.50	-0.70**	-0.11	0.03	-3.58
2	T_2	-0.50	0.27	-0.06	-0.70	0.57*	-0.62	-0.58	0.02	0.03	1.00	0.05	-0.40	0.22	0.24*	0.00	2.79
3	T_3	0.50	-0.17	0.26	0.96	-0.22	-0.81*	-0.66*	-0.73*	-0.31	-1.99**	0.91*	-0.10	0.48*	-0.13	-0.03	0.80
4	L_1	-2.03**	3.10**	-0.99**	-1.48	-0.32	6.45**	5.25**	2.20**	1.65**	4.48**	1.23	-2.15**	0.44	-0.98**	-0.05	-2.69
5	L_2	0.97	1.53**	-0.01	-5.88**	-1.87**	-3.65**	-1.21*	-4.07**	-2.60**	0.45	0.63	-4.53**	-1.60**	0.88**	0.00	0.90
6	L_3	-1.92**	0.98**	-0.86**	2.51**	-0.54	-1.15	1.10*	2.62**	1.55**	0.93	-0.49	1.84**	0.19	-1.84**	-0.06	1.77
7	L_4	0.19	0.69	-0.44	5.27**	3.61**	-2.34**	-1.22*	-2.96**	-2.41**	-8.49**	-3.06**	-3.53**	0.66	0.40	-0.04	-0.79
8	L_5	-0.25	1.49**	0.08	5.28**	4.57**	0.03	-3.15**	-1.67**	-1.22**	-6.72**	-0.67	3.02**	1.37**	-0.03	0.13**	8.55
9	L_6	1.53**	-1.92**	0.36	0.92	-1.56**	1.90**	-0.33	2.25**	1.46**	1.91	0.10	1.05*	0.93**	-0.95**	0.06	3.58
10	L_7	0.19	-4.01**	0.14	-4.78**	-2.33**	-0.70	-1.80**	-1.65**	-1.16**	2.96*	-0.32	0.84	1.57**	0.81**	0.06	-4.88
11	L_8	-1.25*	0.07	-0.49*	-1.12	-2.42**	0.36	2.19**	0.07	0.43	1.41	2.07**	-2.12**	-0.45	0.83**	-0.13**	0.72
12	L_9	-1.36*	-0.27	0.99**	3.58**	0.19	-2.09**	-0.93	0.68	0.23	-2.13	-0.92	4.98**	-1.30**	1.81**	-0.02	-6.06
13	L_{10}	-1.47*	-2.42**	0.57*	-4.43**	-0.04	1.42*	1.69**	2.94**	2.26**	8.45**	1.78*	6.62**	-2.02**	1.73**	0.08	2.07
14	L_{11}	5.53**	-1.18**	0.20	-0.20	2.15**	-2.65**	-3.14**	-4.44**	-3.32**	-6.68**	-2.99**	-11.49**	-1.33**	-0.42	-0.07	-0.26
15	L_{12}	-0.14	1.95**	0.44	0.35	-1.45**	2.42**	1.56**	4.04**	3.14**	3.43**	2.65**	5.47**	1.55**	-2.25**	0.04	-2.90
16	$L_1 \times T_1$	0.78	0.49	0.28	-1.15	0.42	-2.98*	-1.28	-2.48*	-1.77*	-1.90	-0.74	0.26	-2.33**	-0.30	0.09	2.72
17	$L_2 \times T_1$	3.11**	0.77	-0.07	0.52	0.97	-0.78	-1.05	1.26	0.80	2.13	-0.45	0.86	-1.45*	-0.30	0.09	-3.44
18	$L_3 \times T_1$	-0.67	-1.23	0.35	-2.38	0.24	-0.48	0.51	-0.36	-0.20	1.84	0.29	-2.43*	1.24	1.19**	-0.01	2.15
19	$L_4 \times T_1$	-0.78	1.26	-0.24	-2.53	-1.98*	1.12	-0.42	2.21*	1.26	5.36*	-0.36	2.93**	-1.26	-0.35	0.03	-2.44
20	$L_5 \times T_1$	0.00	1.37	-0.42	-0.54	-1.74	-0.66	-2.91**	-1.64	-1.03	-1.93	-0.00	0.63	-3.31**	-1.95**	0.02	-7.74
21	$L_6 \times T_1$	1.22	-0.75	0.01	-0.66	1.48	-7.00**	-4.99**	-3.44**	-2.48**	-3.49	-1.27	-3.89**	2.05**	0.93*	0.12	2.19
22	$L_7 \times T_1$	-1.11	-0.40	-0.78	-0.01	-0.11	1.24	2.34*	0.57	0.46	1.29	0.43	0.62	1.03	0.52	-0.02	-2.80
23	$L_8 \times T_1$	0.00	-0.94	-0.45	-1.34	-1.45	-0.42	0.32	-1.45	-1.40	-0.16	-2.44	-0.07	1.48*	1.33**	-0.05	1.70
24	$L_9 \times T_1$	0.78	1.04	-0.24	3.33	0.97	-1.77	0.81	-0.23	0.05	-2.99	1.16	1.48	3.57**	0.23	-0.05	-1.62
25	$L_{10} \times T_1$	-0.44	-1.17	0.39	2.85	2.05*	6.73**	3.29**	2.49*	2.05**	-0.50	1.93	-2.84**	0.57	-0.38	-0.06	5.88
26	$L_{11} \times T_1$	-1.78	0.41	0.02	-0.33	-2.24*	0.20	1.08	0.78	0.49	2.18	-0.04	3.76**	-2.04**	-0.27	-0.10	2.92
27	$L_{12} \times T_1$	-1.11	-0.84	1.15*	2.25	1.40	4.80**	2.32*	2.30*	1.77*	-1.84	1.50	-1.30	0.46	-0.65	-0.08	0.49
28	$L_1 \times T_2$	0.28	0.19	0.05	-1.94	-0.74	3.53**	1.43	1.52	0.99	3.73	0.06	1.73	-0.36	0.02	-0.03	-6.04
29	$L_2 \times T_2$	-1.72	0.83	0.16	0.05	-0.15	0.60	1.05	0.51	0.15	0.98	-1.41	-1.19	3.33**	0.31	-0.15	2.71
30	$L_3 \times T_2$	0.50	-0.50	-0.25	1.90	-3.26**	2.92*	1.63	0.16	-0.02	-1.91	-0.59	0.30	-2.59**	-0.42	0.04	-1.38

Continued

Table 4.4.5 Continued.,...

SN	Genotype	Days to flowering	Height of main axis	Primary branches per plant	Haulm yield per plant	Barren pegs per plant	Total pods per plant	Mature pods per plant	Pod yield per plant	Kernel yield per plant	Harvest index	Shelling percent	100-Kernel weight	Oil content	Protein content	Chloro-phyll content	Chlorophyll stability index
31	$L_4 \times T_2$	-0.28	-3.01**	-0.43	1.89	3.40**	1.94	-0.09	-2.33*	-1.43	-5.22*	-0.09	0.05	0.21	-0.29	-0.05	4.78
32	$L_5 \times T_2$	0.83	-0.39	0.09	1.86	4.48**	-1.53	1.40	1.29	1.14	-0.22	1.78	-0.87	2.50**	1.31**	-0.05	17.30
33	$L_6 \times T_2$	-0.61	0.38	-0.32	-0.91	-2.56*	-1.33	1.05	0.62	0.20	1.38	-0.80	1.85	0.49	-1.38**	-0.01	-5.02
34	$L_7 \times T_2$	-0.94	0.51	0.55	-1.10	1.61	1.95	-0.71	0.92	0.57	2.71	-0.15	0.56	-1.73*	1.96**	-0.00	-2.56
35	$L_8 \times T_2$	-0.17	0.34	0.15	-0.67	-2.10*	0.21	-1.19	-0.90	-0.38	-0.78	1.28	0.56	0.50	-1.14**	-0.02	-1.19
36	$L_9 \times T_2$	-0.39	-1.13	0.50	-0.08	0.60	-0.06	-0.10	0.64	0.33	0.57	-0.31	-0.16	-1.14	-1.45**	0.04	-2.41
37	$L_{10} \times T_2$	0.06	-0.34	-0.11	-1.30	-1.79	-5.87**	-2.30*	-0.75	-0.35	0.83	0.96	0.17	-1.29	0.80	0.05	-4.81
38	$L_{11} \times T_2$	0.39	0.15	-0.27	0.44	2.12*	-0.67	-0.98	-0.41	-0.26	-1.67	-0.19	-1.15	0.37	-0.01	0.06	-7.57
39	$L_{12} \times T_2$	2.06	2.97**	-0.12	-0.14	-1.61	-1.69	-1.20	-1.26	-0.95	-0.40	-0.54	-1.83	-0.29	0.29	0.11	6.19
40	$L_1 \times T_3$	-1.06	-0.67	-0.33	3.09	0.32	-0.55	-0.15	0.96	0.78	-1.84	0.69	-1.99	2.69**	0.28	-0.06	3.33
41	$L_2 \times T_3$	-1.39	-1.59*	-0.09	-0.57	-0.82	0.18	0.00	-1.77	-0.95	-3.11	1.86	0.33	-1.89**	-0.01	0.05	0.73
42	$L_3 \times T_3$	0.17	1.73*	-0.10	0.48	3.03**	-2.44*	-2.14	0.21	0.22	0.07	0.30	2.13*	1.34	-0.77	-0.03	-0.77
43	$L_4 \times T_3$	1.06	1.75*	0.67	0.65	-1.41	-3.05*	0.52	0.12	0.16	-0.13	0.45	-2.97**	1.05	0.63	0.01	-2.34
44	$L_5 \times T_3$	-0.83	-0.98	0.33	-1.32	-2.74**	2.19	1.51	0.35	-0.11	2.15	-1.78	0.24	0.81	0.65	0.03	-9.56
45	$L_6 \times T_3$	-0.61	0.37	0.31	1.58	1.08	8.33**	3.94**	2.83**	2.28**	2.11	2.07	2.04	-2.54**	0.45	-0.11	2.83
46	$L_7 \times T_3$	2.06	-0.11	0.23	1.11	-1.50	-3.20**	-1.63	-1.49	-1.03	-4.01	-0.28	-1.18	0.71	-2.48**	0.02	5.36
47	$L_8 \times T_3$	0.17	0.61	0.30	2.01	3.55**	0.21	0.87	2.35*	1.79*	0.94	1.17	-0.49	-1.97**	-0.19	0.07	-0.51
48	$L_9 \times T_3$	-0.39	0.09	-0.26	-3.25	-1.57	1.83	-0.70	-0.41	-0.38	2.42	-0.84	-1.32	-2.43**	1.22**	0.01	4.03
49	$L_{10} \times T_3$	0.39	1.51*	-0.27	-1.55	-0.27	-0.86	-0.99	-1.74	-1.70*	-0.33	-2.89	2.68*	0.72	-0.42	0.01	-1.07
50	$L_{11} \times T_3$	1.39	-0.56	0.25	-0.11	0.12	0.47	-0.10	-0.37	-0.24	-0.51	0.23	-2.61*	1.67*	0.29	0.04	4.65
51	$L_{12} \times T_3$	-0.94	-2.13**	-1.03*	-2.11	0.21	-3.11*	-1.12	-1.04	-0.82	2.24	-0.96	3.14**	-0.17	0.36	-0.04	-6.68
S.E.	GCA_{Ti}	0.31	0.20	0.13	0.49	0.27	0.33	0.30	0.28	0.22	0.65	0.43	0.29	0.19	0.12	0.03	2.59
	GCA_{Lj}	0.56	0.36	0.24	0.89	0.49	0.60	0.54	0.51	0.39	1.18	0.77	0.53	0.34	0.21	0.05	4.68
	GCA_{Ti-j}	0.38	0.24	0.16	0.60	0.33	0.41	0.37	0.34	0.26	0.80	0.53	0.36	0.23	0.14	0.03	3.18
	GCA_{Li-j}	0.77	0.49	0.33	1.21	0.66	0.82	0.74	0.69	0.53	1.60	1.05	0.72	0.47	0.29	0.07	6.35
	GCA_{Ti-Lj}	0.61	0.39	0.26	0.95	0.52	0.64	0.58	0.54	0.42	1.27	0.83	0.57	0.37	0.23	0.05	5.02
	SCA_{ij}	1.13	0.72	0.48	1.78	0.98	1.20	1.08	1.01	0.78	2.36	1.55	1.05	0.69	0.43	0.10	9.35
	SCA_{Ti-Tj}	1.38	0.88	0.59	2.18	1.20	1.47	1.33	1.24	0.95	2.89	1.90	1.29	0.84	0.52	0.12	11.45
	SCA_{Li-Lj}	1.53	0.98	0.65	2.41	1.33	1.63	1.47	1.38	1.05	3.20	2.10	1.43	0.93	0.58	0.14	12.71
	SCA_{Ti-Lj}	1.58	1.01	0.67	2.49	1.37	1.68	1.52	1.42	1.09	3.30	2.17	1.47	0.96	0.60	0.14	13.10

*,** Significant at 5% and 1%, respectively.

4.4.1 Days to flowering :

Analysis of variance revealed significant difference among GCA of testers but none of tester exhibited significant GCA effects. GCA effects of lines differ significantly and good general combiner line for early flowering was L_1 (–2.03). Other lines having GCA effects at par to L_1 were L_3, L_{10}, L_9 and L_8. Line L_{11} and L_6 were poor general combiner as they were having positive GCA effects.

SCA effects of hybrids differ significantly. None of the hybrid was good specific combiner for early flowering where as $L_2 \times T_1$ (3.11) was the poor specific combiner for early flowering.

4.4.2 Height of main axis :

GCA effects of lines differ significantly and good general combiner for short stature was L_7 (–4.01). Other lines having significant good GCA effects were L_{10}, L_6 and L_{11}. The line L_1, L_{12}, L_2, L_5 and L_3 were poor general combiner for hight of main axis.

Hybrid $L_4 \times T_2$ (–3.01), $L_{12} \times T_3$ (–2.13) and $L_2 \times T_3$ (–1.59) were good specific combiner whereas $L_{12} \times T_2$ (2.97), $L_4 \times T_3$ (1.75), $L_3 \times T_3$ (1.73) and $L_{10} \times T_3$ (1.51) were poor combiners.

4.4.3 Primary branches per plant :

Analysis of variance revealed significant difference among GCA of testers and lines but, none of tester exhibited significant GCA effects. Among the lines L_9 (0.99) and L_{10} (0.57) were good general combiner for more number of primary branches per plant. Two lines L_1 and L_3 were poor general combiner for primary branches per plant.

SCA effects of hybrids differ significantly. The cross $L_{12} \times T_1$ (1.15) was good and $L_{12} \times T_3$ (–1.03) was poor specific combiner for this trait.

4.4.4 Haulm yield per plant :

Analysis of variance revealed significant difference among GCA of lines and testers but, none of tester exhibited significant GCA effects. Among lines L_5 (5.28), L_4 (5.27), L_9 (3.58) and L_3 (2.51) were good general combiners whereas, L_2 (–5.88), L_7 (–4.78) and L_{10} (–4.43) were poor combiners for haulm yield per plant. The SCA effects was not significant in any cross.

4.4.5 Barren pegs per plant :

For less number of barren pegs per plant L_8 (–2.42), L_7 (–2.33), L_2 (–1.87), L_6 (–1.56) and L_{12} (–1.45) were good and L_5 (4.57) L_4 (3.61), L_{11} (2.15) and T_2 (0.57) were poor general combiners.

The crosses $L_3 \times T_2$ (–3.26), $L_5 \times T_3$ (–2.74), $L_6 \times T_2$ (–2.56), $L_{11} \times T_1$ (–2.24), $L_8 \times T_2$ (–2.10) and $L_4 \times T_1$ (–1.98) were good and $L_5 \times T_2$ (4.48), $L_8 \times T_3$ (3.55), $L_4 \times T_2$ (3.40), $L_3 \times T_3$ (3.03), $L_{11} \times T_2$ (2.12) and $L_{10} \times T_1$ (2.05) were poor specific combiner for this trait.

4.4.6 Total pods per plant :

GCA effects among lines as well as testers differ significantly. T_1 (1.42) was good and T_3 (–0.81) was poor general combiner for bearing more total pods per plant. Among lines L_1 (6.45), L_{12} (2.42), L_6 (1.90) and L_{10} (1.42) were good and L_2 (–3.65), L_{11} (–2.65), L_4 (–2.34) and L_9 (–2.09) were poor general combiner.

SCA effects of hybrids differ significantly. For total pods per plant good specific combiner crosses were $L_6 \times T_3$ (8.33), $L_{10} \times T_1$ (6.73), $L_{12} \times T_1$ (4.80), $L_1 \times T_2$ (3.53) and $L_3 \times T_2$ (2.92) while poor specific combiners were $L_6 \times T_1$ (–7.00), $L_{10} \times T_2$ (–5.87), $L_7 \times T_3$ (–3.20), $L_{12} \times T_3$ (–3.11), $L_4 \times T_3$ (–3.05), $L_1 \times T_1$ (–2.98) and $L_3 \times T_3$ (–2.44).

4.4.7 Mature pods per plant :

For mature pods per plant one tester viz., T_1 (1.23) and five lines viz., L_1 (5.25), L_8 (2.19), L_{10} (1.69), L_{12} (1.56) and L_3 (1.10) were good and one tester viz., T_3 (–0.66) and five lines viz., L_5 (–3.15), L_{11} (–3.14), L_7 (–1.80), L_4 (–1.22) and L_1 (–1.21) were poor general combiner.

Hybrid $L_6 \times T_3$ (3.94), $L_{10} \times T_1$ (3.29), $L_7 \times T_1$ (2.34) and $L_{12} \times T_1$ (2.32) were good and $L_6 \times T_1$ (–4.98), $L_5 \times T_1$ (–2.91) and $L_{10} \times T_2$ (–2.30) were poor specific combiners for more number of mature pods per plant.

4.4.8 Pod yield per plant :

Analysis of variance revealed significant difference among GCA of testers and lines. Among testers for more pod yield T_1 (0.71) was good and T_3 (–0.73) was poor general combiner. Among lines L_{12} (4.04), L_{10} (2.94), L_3 (2.62), L_6 (2.25) and L_1 (2.20) were good and L_{11} (–4.44), L_2 (–4.07), L_4 (–2.96), L_5 (–1.67) and L_7 (–1.65) were poor general combiner.

Significant positive SCA effects was in $L_6 \times T_3$ (2.83), $L_{10} \times T_1$ (2.49), $L_8 \times T_3$ (2.35), $L_{12} \times T_1$ (2.30) and $L_4 \times T_1$ (2.21) and negative in $L_6 \times T_1$ (–3.44), $L_1 \times T_1$ (–2.48) and $L_4 \times T_2$ (–2.33).

4.4.9 Kernel yield per plant :

Analysis of variance revealed significant difference among GCA effects of lines. Ten lines exhibited significant GCA effects five each in positive viz., L_{12} (3.14), L_{10} (2.26), L_1 (1.65), L_3 (1.55) and L_6 (1.46) and negative viz., L_{11} (–3.32), L_2 (–2.60), L_4 (–2.41), L_5 (–1.22) and L_7 (–1.16) directions.

SCA effects of hybrids differ significantly. The cross $L_6 \times T_3$ (2.28) had highest SCA effects in positive direction followed by $L_{10} \times T_1$ (2.05), $L_8 \times T_3$ (1.79) and $L_{12} \times T_1$ (1.77). Significant SCA effects in negative direction was

observed in three hybrids viz., L_6 x T_1 (–2.48), L_1 x T_1 (–1.77) and L_{10} x T_3 (–1.70).

4.4.10 Harvest index :

Analysis of variance revealed significant difference among GCA of testers and lines. None of the tester was good general combiner for higher harvest index though T_3 (–1.99) was poor general combiner. Among lines L_{10} (8.45), L_1 (4.48), L_{12} (3.43) and L_7 (2.96) were good and L_4 (–8.49), L_5 (–6.76) and L_{11} (–6.68) were poor general combiners.

SCA effects of hybrids differ significantly. Hybrid L_4 x T_1 (5.36) was good and L_4 x T_2 (–5.22) was poor specific combiner for harvest index.

4.4.11 Shelling per cent :

Analysis of variance revealed significant difference among GCA effects of testers as well as lines. Among testers T_3 (0.91) was good general combiner for higher shelling per cent whereas, T_1 (–0.96) was poor combiner. Maximum positive significant GCA effects among lines was recorded in L_{12} (2.65). Other lines having significant positives GCA effects were L_8 (2.07) and L_{10} (1.78). Significant GCA effects in negative direction was observed in L_4 (–3.06) and L_{11} (–2.99). Difference in SCA effects of hybrids was non–significant.

4.4.12 100–Kernel weight :

GCA effects of lines and testers differs significantly but none of tester exhibited significant GCA effects. Six lines viz., L_{10} (6.62), L_{12} (5.47), L_9 (4.98), L_5 (3.02), L_3 (1.84) and L_6 (1.05) had significant positive GCA effects and five lines viz., L_{11} (–11.49), L_2 (–4.53), L_4 (–3.53), L_1 (–2.15) and L_8 (–2.12) had significant negative effects for 100–kernel weight.

Magnitude of SCA effects in hybrids differ significantly and it was positive significant in hybrids viz., L_{11} x T_1 (3.76), L_{12} x T_3 (3.14), L_4 x T_1 (2.93), L_{10} x T_3 (2.68) and L_3 x T_3 (2.13) and negative significant in hybrids viz., L_6 x T_1 (–3.89), L_4 x T_3 (–2.97), L_{10} x T_1 (–2.84), L_{11} x T_3 (–2.61) and L_3 x T_1 (–2.43).

4.4.13 Oil content :

For oil content T_3 (0.48), L_7 (1.57), L_{12} (1.55), L_5 (1.37) and L_6 (0.93) were good general combiner and T_1 (–0.70), L_{10} (–2.02), L_2 (–1.60), L_{11} (–1.33) and L_9 (–1.30) were poor general combiners.

SCA effects of hybrids differ significantly. Cross L_9 x T_1 (3.57) had highest significant positive SCA effects for oil content. Six other crosses having positive SCA effects viz., L_2 x T_2 (3.33), L_1 x T_3 (2.69), L_5 x T_2 (2.50), L_6 x T_1 (2.05), L_{11} x T_3 (1.67) and L_8 x T_1 (1.48). Significant negative SCA effects was observed in 10 crosses viz., L_5 x T_1 (–3.31), L_3 x T_2 (–2.59), L_6 x T_3 (–2.54), L_9 x T_3 (–2.43), L_1 x T_1 (–2.33), L_{11} x T_1 (–2.04), L_8 x T_3 (–1.97), L_2 x T_3 (–1.89), L_7 x T_2 (–1.73) and L_2 x T_1 (–1.45).

4.4.14 Protein content :

GCA effects of testers as well as lines differs significantly. T_2 (0.24), L_9 (1.81), L_{10} (1.73), L_2 (0.88), L_8 (0.83) and L_7 (0.81) were good general combiner for more protein content and L_{12} (–2.25), L_3 (–1.84), L_1 (–0.98) and L_6 (–0.95) were poor general combiners.

Significant differences was recorded among SCA effects of hybrids. L_7 x T_2 (1.96) had highest positive SCA effect. Other six hybrids having significant positive SCA effects were L_8 x T_1 (1.33), L_5 x T_2 (1.31), L_9 x T_3 (1.22), L_3 x T_1 (1.19) and L_6 x T_1 (0.93). Five hybrids had significant

negative SCA effects for protein content were L_7 x T_3 (–2.48), L_5 x T_1 (–1.95), L_9 x T_2 (–1.45), L_6 x T_2 (–1.38) and L_8 x T_2 (–1.44).

4.5 Correlation Studies (Tables 4.5)

Genotypic and phenotypic correlation coefficients were calculated among characters having significant difference among genotypes. Such difference was significant for all characters except chlorophyll stability index.

A perusal of table 4.5 indicated that genotypic and phenotypic correlation coefficients showed similar trend in all characters except that positive significant correlation was observed between primary branches per plant and pod yield per plant (r = 0.24), primary branches per plant and protein content (r=0.19) and between haulm yield per plant and oil content (0.23) was significant only at phenotypic level. However, magnitude of genotypic correlation was higher. Therefore, in ensuing para only genotypic correlations will be discussed or presented.

The main objectives of this experiment was pod yield improvement therefore, results of correlations are discussed in this light only. The total pods per plant (r = 0.66); mature pods per plant (r = 0.75), kernel yield per plant (r = 0.99), harvest index (r = 0.74), shelling per cent (r = 0.52) and 100–kernel weight (r = 0.65) had significant positive correlation with pod yield per plant whereas correlation of days to flowering (r = –0.59) was negatively significant with pod yield per plant.

The mutual correlation among characters having significant positive correlations with pod yield, was also positive and significant except 100–kernel weight which showed non significant correlations with total pods and mature pods per plant. Correlations of days to flowering with all these characters was also negative as it had with pod yield per plant.

Table 4.5 **Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients among different characters in groundnut**

Character		Days to flowering	Height of main axis	Primary branches per plant	Haulm yield per plant	Barren pegs per plant	Total pods per plant	Mature pods per plant	Pod yield per plant	Kernel yield per plant	Harvest index	Shelling percent	100-Kernel weight	Oil content	Protein content	Chlorophyll Content
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1	r		0.18	0.12	0.11	0.30*	-0.43**	-0.54**	-0.59**	-0.61**	-0.59**	-0.52**	-0.65**	-0.13	-0.28	0.04
	SE		0.15	0.18	0.16	0.14	0.13	0.12	0.11	0.10	0.11	0.13	0.09	0.15	0.14	0.25
2	r	0.17		-0.32*	0.34*	0.29*	-0.13	0.03	-0.01	-0.01	-0.23	-0.09	-0.08	-0.04	-0.44**	-0.23
	SE	0.11		0.15	0.14	0.13	0.14	0.15	0.15	0.15	0.14	0.16	0.14	0.15	0.12	0.23
3	r	0.01	-0.19*		0.04	0.05	0.18	-0.07	0.30	0.34*	0.16	0.41*	0.29	0.08	0.28	0.33
	SE	0.08	0.09		0.18	0.17	0.16	0.17	0.16	0.15	0.17	0.17	0.15	0.17	0.16	0.27
4	r	0.05	0.25*	0.15		0.57**	0.01	-0.06	0.03	0.01	-0.65**	-0.08	0.03	0.26	-0.36**	-0.14
	SE	0.10	0.10	0.09		0.11	0.15	0.16	0.15	0.15	0.09	0.17	0.15	0.14	0.13	0.24
5	r	0.20	0.24*	0.07	0.51**		-0.16	-0.37**	-0.22	-0.22	-0.56**	-0.25	-0.14	0.20	-0.16	0.01
	SE	0.10	0.11	0.10	0.08		0.14	0.13	0.14	0.14	0.11	0.15	0.14	0.14	0.14	0.23
6	r	-0.33**	-0.11	0.12	0.01	-0.11		0.72**	0.66**	0.66**	0.46**	0.42**	0.25	0.06	-0.07	-0.07
	SE	0.09	0.12	0.10	0.11	0.12		0.07	0.09	0.09	0.12	0.14	0.13	0.15	0.14	0.23
7	r	-0.46**	0.02	-0.05	-0.06	-0.28**	0.68**		0.75**	0.73**	0.61**	0.36*	0.21	-0.04	-0.06	-0.57*
	SE	0.08	0.12	0.09	0.11	0.10	0.06		0.07	0.07	0.10	0.14	0.14	0.15	0.15	0.22
8	r	-0.46**	0.00	0.24**	0.05	-0.19	0.59**	0.64**		0.99**	0.74**	0.52**	0.65**	0.07	-0.12	-0.06
	SE	0.08	0.12	0.09	0.11	0.11	0.07	0.06		0.00	0.07	0.12	0.09	0.15	0.14	0.23
9	r	-0.48**	-0.00	0.26**	0.04	-0.18	0.60**	0.63**	0.97**		0.74**	0.65**	0.67**	0.11	-0.10	-0.06
	SE	0.08	0.12	0.09	0.11	0.11	0.07	0.06	0.00		0.07	0.10	0.08	0.15	0.14	0.23
10	r	-0.40**	-0.16	0.06	-0.65**	-0.50**	0.39**	0.50**	0.67**	0.67**		0.46**	0.52**	-0.11	0.23	0.07
	SE	0.08	0.11	0.09	0.06	0.08	0.09	0.08	0.06	0.06		0.14	0.11	0.15	0.14	0.24
11	r	-0.35**	-0.02	0.19*	-0.07	-0.15	0.30**	0.27**	0.40**	0.57**	0.35**		0.50**	0.20	0.10	0.10
	SE	0.07	0.11	0.07	0.09	0.10	0.09	0.09	0.08	0.06	0.08		0.12	0.15	0.16	0.26
12	r	-0.50**	-0.06	0.19	0.03	-0.11	0.23	0.18	0.58**	0.59**	0.42**	0.38**		0.02	0.09	0.53*
	SE	0.08	0.12	0.10	0.12	0.12	0.12	0.12	0.08	0.08	0.09	0.09		0.14	0.14	0.21
13	r	-0.06	-0.01	0.06	0.23*	0.19	0.05	-0.03	0.09	0.12	-0.09	0.17	0.02		-0.20	-0.14
	SE	0.11	0.12	0.10	0.10	0.11	0.12	0.11	0.12	0.11	0.11	0.10	0.12		0.14	0.23
14	r	-0.19	-0.37**	0.19*	-0.24*	-0.12	-0.08	-0.08	-0.10	-0.08	0.17	0.07	0.08	-0.12		0.21
	SE	0.11	0.10	0.10	0.10	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.13	0.12		0.23
15	r	0.03	-0.08	0.09*	-0.07	-0.01	-0.02	-0.21**	-0.04	-0.05	0.02	-0.06	0.21**	-0.04	0.08	
	SE	0.06	0.08	0.03	0.06	0.08	0.08	0.06	0.08	0.07	0.07	0.05	0.08	0.08	0.08	

*, ** Significant at 5% and 1%, respectively.

Other remaining characters viz., barren pegs per plant, primary branches per plant, haulm yield per plant and chlorophyll content though not had correlations with pod yield but they showed correlation with pod yield correlated characters. Significant positive correlation was observed between barren pegs and days to flowering (r = 0.30), primary branches per plant with kernel yield per plant (r = 0.34) and shelling per cent (g = 0.41) and chlorophyll content with 100–kernel weight (r = 0.53) whereas, negative correlation was observed between barren pegs per plant and mature pods per plant (r = –0.37) and between haulm yield per plant and harvest index (r = –0.65). Barren pegs per plant showed positive significant correlations with height of main axis (r = 0.29) and haulm yield per plant (r = 0.57). Height of main axis was negatively correlated with primary branches per plant (r = –0.32) and protein content (r = –0.44) while positively with haulm yield per plant (r = 0.34). Negative correlation was also observed between haulm yield and protein content (r = –0.36).

4.6 Path Analysis (Table 4.6)

For path coefficient of seven correlated characters towards pod yield calculation of residual effect was not possible as R^2 was negative (Appendix V). To findout the reason behind it, different characters were dropped one by one. Value of residual effect was 0.37 and 0.15 when kernel yield and shelling per cent were dropped, respectively. When both these characters dropped simultaneously the residual effect was 0.37 i.e. equal to the drops of kernel yield per plant. The residual effect was remained 0.15 when harvest index was dropped with shelling per cent. On the basis of these five characters viz., days to flowering, total pods per plant, mature pods per

Table 4.6 Path analysis for pod yield per plant in groundnut

Characters	Days to flowering	Total pods per plant	Mature pods per plant	Kernel yield per plant	100-kernel weight	Genotypic correlation coefficient with pod yield per plant
Days to flowering	0.05	0.00	-0.06	-0.56	-0.03	-0.59
Total pods per plant	-0.02	-0.02	0.08	0.61	0.01	0.66
Mature pods per plant	-0.03	-0.01	0.11	0.67	0.01	0.75
Kernel yield per plant	-0.03	-0.01	0.08	0.92	0.03	0.99
100-kernel weight	-0.03	-0.00	0.02	0.61	0.05	0.65

Res. Effect: 0.15

plant, kernel yield per plant and 100–kernel weight were identified to calculate the direct and indirect effect towards pod yield per plant (Table 4.6.1). The value of direct effect was maximum for kernel yield per plant followed by mature pods per plant, 100–kernel weight, days to flowering and total pods per plant. The indirect effect of all these traits also followed the same trend.

5. DISCUSSION

The prime importance of plant breeding programme is to increase the yield potential of a crop. Yield improvement in groundnut evades a major breakthrough on account of many inherent factors associated with the crop like allopolyploidy, subterranean fruiting habit, lack of reliable correlation between aerial vegetative parts and underground productive parts, cumbersome hybridization procedure and consequently low seed set (Rathnaswamy, 1980; Prasad, 1994; Stalker, 1997).

Success of any breeding programme depends upon magnitude of genotypic variability present. After exhausting it, hybridization can be used to create new variability. The other means of creating variability are mutation and somaclonal variations. In general, heterozygotes are superior than homozygotes but easily exploited only in cross-pollinated crops or in self-pollinated crops where the male-sterility system is available. In self-pollinated crops other possibility left is selection of transgressive segregants in segregating generations of heterotic crosses (Pungle, 1983; Arunachalam *et al.*, 1984; Makne and Bhale, 1987). To obtain higher gains, selection of parents alongwith information about nature and magnitude of gene effects controlling various traits is important (Comstock and Robinson, 1952).

Keeping these in view, the present investigation was undertaken to study heterosis, combining ability and character association in 16 characters. F_1s were generated by mating 12 lines with 3 testers. The lines were selected on the basis of different characters viz., there three L_1, L_2, L_3 (ICGV 92195, ICUG 92267, ICUG 92217) were early maturing, three L_4, L_5, L_6 (ICUG 92035, ICUG 92027, ICGV 92023) were medium maturing; two L_7, L_8 (ICGS 44, RG 141) were high yielding; one L_9 (TKG 19A) bold seeded; one

L_{10} (ICGS 93470) fresh seed dormant; and two L_{11}, L_{12} (DMF 11-23, DMF 8-22) were drought tolerant. Testers T_1, T_2 and T_3 (GG-2, TAG-24 and TG-17) were high yielders and widely adapted. The significant findings of this study are discussed below.

Analysis of variance revealed significant difference among genotypes for all the characters except chlorophyll stability index which was not included in further study. This indicates that parents selected for the study were diverse, which is desirable for improvement of yield and its componental traits (Arunanchalam, 1988). The difference between checks was significant for 100-kernel weight and protein content where 100-kernel weight was higher in SB-XI and protein content was higher in JL-24.

Difference among parents was significant for all characters except primary branches per plant. This difference was mainly due to the lines as difference among testers was significant only for five characters viz., height of main axis, barren pegs per plant, shelling per cent, 100-kernel weight and chlorophyll content.

Among lines, testers and checks, tester TAG-24 (T_2) was early to flower, had minimum number of barren pegs, maximum total pods per plant whereas shelling per cent was maximum in check JL-24. For other characters one or other line had outstanding performance. L_3 had maximum pod yield per plant and harvest index, L_7 had minimum height of main axis and maximum protein content. Haulm yield per plant, primary branches per plant, mature pods per plant, kernel yield per plant, 100-kernel weight and oil content was maximum in L_4, L_6, L_8, L_{12}, L_9 and L_5, respectively.

The magnitude of heterosis provides information on the extent of genetic diversity of parents involved in a cross and helps to choose the parents in developing superior F_1s, so as to exploit hybrid vigour. In self-

pollinated crops like groundnut, where commercial hybrid seed production is not feasible, exploitation of hybrid vigour is limited. However, if the heterosis is due to epistatic gene effects, particularly of additive x additive type, due to repulsion phase linked loci, exhibiting partial or complete dominance, it is possible to fix the alleles at interacting state to preserve the heterotic effects in pure lines (Arunachalam *et al.*, 1984). The allopolyploid nature of groundnut will also favour preservation of such hybrid vigour for a considerable number of generations. It is, therefore, desirable to identify the crosses which exhibit hybrid vigour preferably when one of the parent is of acceptable commercial quality and to determine the genetic basis, based on the observed effects (Isleib and Wynne, 1980). In addition, heterotic hybrids can also produce desirable transgressive segregants in their advanced generations (Arunachalam *et al.*, 1984).

Computation of economic heterosis has no genetic significance. Nevertheless, it has been estimated for the purpose of identification of higher *per se* hybrids. In cross pollinated crops such hybrids can be directly utilized for commercial exploitation but in self-pollinated crops, if genetic parameters favour, can be used for selection of transgressive segregants. Heterosis and heterobeltiosis provide information about the distribution of genes and nature of their actions. Hence, investigations on all three types of heterosis were undertaken for all the characters studied.

The difference between average performance of parents and crosses indicated presence of average heterosis in the crosses. Such difference was significant in all the characters except haulm yield per plant, barren pegs per plant and chlorophyll content. The average performance of hybrids was significantly higher than parents for all the characters except days to flowering and height of main axis where mean value of both the characters was less in F_1s. This indicates presence of average heterosis for most of the

characters. Average heterosis for different characters was also reported by Arunachalam (1988), Nagda *et al.* (2001 a) and Vyas *et al.* (2001).

The maximum range of heterosis was observed in barren pegs per plant (-33.18 to 137.93%) followed by kernel yield per plant (-16.62 to 50.39%), pod yield per plant (-16.98 to 46.85%), chlorophyll content (-33.97 to 28.03%), total pods per plant (-13.39 to 44.89%) and primary branches per plant (-9.75 to 47.10%). For rest of the characters deviation of means was less than 50 per cent and was minimum in oil content (-8.25 to 11.09%). Heterosis in both the directions for one or other characters was also reported by Sridharan and Marappan (1980), Arunachalam *et al.* (1982), Basu *et al.* (1986c), Nagda *et al.* (2001a) and Vyas *et al.* (2001). Number of crosses exhibiting heterosis varied from 3 (chlorophyll content) to 25 (oil content). However, in most of the characters numbers of heterotic crosses were more than 10. Nagda *et al.* (2001a) and Vyas *et al.* (2001) also observed number of heterotic crosses for various characters.

The deviation from mid-parent is the indication of presence of non-additive gene action but its practical utility is very low. According to Mather (1949) the crosses are said to be heterotic only when they cross the limit of its parents. However, Fonesca and Patterson (1968) coined the term 'heterobeltiosis' for mean values crossing the limit of parents in desirable direction. Except four crosses viz., $L_4 \times T_1$, $L_{11} \times T_1$, $L_4 \times T_2$ and $L_{11} \times T_2$, all the crosses were heterobeltiotic for one or more characters. These were maximum for primary branches per plant (9) followed by pod yield per plant (8), mature pods, kernel yield, shelling per cent and oil content (7). Maximum heterobeltiosis in these characters was 45, 36.77, 29.89, 44.05, 14.08 and 9.00 per cent, respectively.

The eight crosses viz., $L_{10}xT_1$, $L_{12}xT_1$, L_1xT_2, L_6xT_2, $L_{12}xT_2$, L_1xT_3, L_6xT_3 and L_8xT_3 exhibiting heterobeltiosis for pod yield per plant also

exhibited heterobeltiosis for one or other characters viz., kernel yield per plant, total and mature pods per plant, 100-kernel weight, shelling per cent, primary branches per plant and haulm yield per plant. Similar findings were also reported by Raju (1978), Sridharan and Marappan (1980), Dwivedi *et al.* (1989), Bansal *et al.* (1993), Sudhakar (1995), Varman and Raveendran (1997), Nagda *et al.* (2001a) and Vyas *et al.* (2001). Presence of heterobeltiosis for these crosses suggest distribution of favourable genes in different parents or desirable interaction between genes present in different parents for these characters.

Among heterobeltiotic crosses, economic heterosis was significant only in eight crosses for one or the other characters (Table 5.1). A perusal of this table revealed that crosses $L_{12}xT_1$ and $L_{10}xT_1$ for pod yield per plant, $L_{12}xT_1$, $L_{10}xT_1$, $L_6 \times T_3$ and L_1xT_2 for kernel yield per plant, $L_{10}xT_1$, L_1xT_2, L_1xT_1 and $L_{12}xT_1$ for mature pods per plant, $L_{10}xT_1$, L_1xT_2, $L_6 \times T_3$ and $L_{12}xT_1$ for total pods per plant, L_5xT_2 and L_1xT_3 for oil content and L_9xT_2 and $L_{12}xT_1$ for primary branches per plant had economic heterosis. Economic heterosis for these one or other character was also reported by Patil, 1973; Garet, 1976; Manoharan *et al.*, 1990; Bansal *et al.*, 1993; Sudhakar, 1995; Nagda *et al.*, 2001a and Vyas *et al.*, 2001.

The heterotic crosses can not be utilized in a proper way unless the cause of heterosis is known. To obtain the same, sum of squares of hybrids has been further partitioned in sum of squares due to GCA of lines and testers and SCA. In sum of squares of hybrid, maximum contribution was from GCA of lines than SCA for all the characters except total pods per plant and oil content where SCA contributed maximum and GCA of lines stands at second position. Contribution of GCA of testers was minimum in all the characters. Upadhyaya *et al.* (1992) also reported minimum contribution of testers towards total variance of hybrids.

Table 5.1 Economic heterosis for different characters in groundnut

Crosses	Primary branches per plant	Total pods per plant	Mature pods per plant	Pod yield per plant	Kernel yield per plant	Oil content
L_1xT_1			12.21* (HxA)			
$L_{10}xT_1$		**22.63**** **(HxA)**	**16.38**** **(HxA)**	**19.17**** **(HxH)**	**32.37**** **(HxA)**	
$L_{12}xT_1$	**23.17*** **(HxA)**	**19.76**** **(HxA)**	**11.83*** **(HxA)**	**23.58**** **(HxH)**	**37.22**** **(HxA)**	
L_1xT_2		**21.97**** **(HxA)**	15.95** (HxA)		16.84* (HxA)	
L_5xT_2						**4.19**** **(HxA)**
L_9xT_2	**23.78*** **(AxL)**					
L_1xT_3		8.95* (HxA)				**3.25*** **(AxH)**
L_6xT_3		**22.17**** **(HxA)**			**23.01**** **(HxA)**	

*,** Significant at 5% and 1%, respectively

Bold indicates significant **SCA**

H Parent with high GCA

A Parent with non-significant GCA

L Parent with low GCA

Estimation of variance depends on the model in use. If selected parents are a random sample of a population and statement is to be made about populations, random effect model is applicable (Kempthrone, 1957). According to this model variances due to GCA of lines was higher for all the characters except barren pegs per plant where variance due to SCA was higher whereas for protein content GCA of lines and SCA variances were equal. Therefore, additive gene action was pre dominant for all the characters except barren pegs per plant and total pods per plant where non-additive gene action was predominant. For protein content contribution of additive as well as non-additive gene actions were equally important. Makne *et al.* (1994) also reported additive and non-additive gene action equally important for protein content. Sandhu and Khehra (1976), Sridharan and Marappan (1980), Manoharan *et al.* (1985), Basu *et al.* (1986a), Varman and Parasivam (1992) and Vindhiyavarman and Raveendran (1994) also reported importance of additive gene action in inheritance of aforesaid characters. For total pods per plant and oil content only SCA variance was significant suggest sole control of non-additive gene action.

If breeding methodology is to be suggested only for the material under study, fixed effect model is to be used. In present investigation selection of parents was done on the basis of their mean for different characters and breeding methodology is also suggested for this material only, the fixed effect model is appropriate. According to this model sum of variance due to GCA of lines was higher for all the characters where hybrid mean square was significant except oil content, total pods per plant, barren pegs per plant, protein content and mature pods per plant where sum of SCA variances was higher.

The correlation between *per se* performance of lines with hybrids also provided information about the presence of dominant and recessive genes in lines or testers. Correlation between *per se* performance of lines and their crosses with all testers was significant positive for 100-kernel weight, pod yield per plant, kernel yield per plant, harvest index and mature pods per plant and no correlation was observed for oil content, shelling per cent and total pods per plant. This indicates presence of dominant genes in lines for former characters and recessive genes for later characters. Such correlation was also significant in T_1 and T_2 for barren pegs per plant, days to flowering and height of main axis, in T_2 and T_3 for haulm yield per plant and in T_1 for protein content and primary branches per plant. This indicates the presence of recessive genes in these testers for above traits.

Among the testers, T_3 was good general combiner for shelling per cent and oil content, T_1 for pod yield per plant and T_2 for protein content. Among lines L_1, L_3, L_5, L_{10} and L_{12} were good general combiner for pod yield as well as kernel yield per plant. Most of these lines also had significant GCA effects for mature pods, 100-kernel weight and total pods per plant. GCA effects of these lines were also significant for one or other character under study. The high GCA effects are observed primarily due to additive and additive x additive gene effects (Griffing, 1956).

Deviation of a hybrid from general performance of its parents in series of crosses is known as specific combining ability (Sprague and Tatum, 1942). Such deviation was significant in one or more hybrids for all the characters except haulm yield per plant and shelling per cent where none of the cross had significant SCA effect. Out of 36 hybrids, 25 were good specific combiners for one or more characters except days to flowering. For pod yield per plant five crosses viz., L_6xT_3, $L_{10}xT_1$, L_8xT_3, $L_{12}xT_1$ and L_4xT_1 had significant SCA effects. Most of these crosses also exhibited significant

SCA effects for kernel yield per plant, mature and total pods per plant. This indicates role of non-additive gene effects in expression of characters in these crosses as also reported by Sandhu and Khehra (1976), Manoharan *et al.* (1985), Upadhyaya *et al.* (1992), Francies and Ramalingam (1999) and Mathur *et al.* (2000) for one or other aforesaid characters.

In segregating generations it is very difficult to obtain the genotypes superior than F_1. Therefore, to select superior genotypes *per se* of F_1 is very important. The crosses are not useful unless they exhibit economic heterosis. In present study eight crosses exhibited economic heterosis for different characters. All these crosses involve atleast one good combiner parent. The SCA effects of these crosses were also significant except L_1xT_2 for kernel yield per plant and mature pods per plant, L_1xT_1 for mature pods per plant and L_1xT_3 for total pods per plant. Therefore, these three crosses can throw transgressive segregants for these characters in segregating generations and can be used in the future breeding programmes. Among crosses had significant SCA effects, two crosses viz., L_{12} x T_1 and L_{10} x T_1 were involving both the parents with good GCA effects for pod yield per plant. According to Shanmugasundaram and Sree Rangasamy (1994) and Singh and Singh (1996) such crosses can also throw transgressive segregants in segregating generations.

There is ample evidence to show that direct selection for yield in underground crop is not easy, especially in groundnut. Thus, any morphological character associated with higher pod yield or contributing to yielding ability would be useful. In present investigation out of 15 characters having significant difference among genotypes, six characters viz., kernel yield per plant, mature pods per plant, total pods per plant, harvest index, shelling percent and 100-kernel weight were positively and days to flowering was negatively correlated with pod yield per plant. All

positively correlated characters also had positive correlation among themselves and negative correlation with days to flowering. This correlation study indicates scope for deciding selection criteria for development of high yielding early maturing genotypes.

Positive correlations of these one or more characters was also reported by Deshmukh *et al.* (1986), Reddy *et al.* (1986), Vaddoria and Patel (1992), Reddy and Gupta (1992), Bhagat *et al.* (1993), Sumathi and Ramnathan (1995) and Nagda *et al.* (2001 b). The negative correlation of pod yield per plant with days to flowering was also observed by Yadav *et al.* (1984), Deshmukh *et al.* (1986) and Nagda *et al.* (2001b).

In general, the genotypic correlation was higher than phenotypic correlation indicating that influence of environment was higher on variance than its effect on covariance. Similar findings were also observed by Yadav *et al.* (1984), Reddy and Gupta (1992) and Nagda *et al.* (2001b).

Further, the path coefficient analysis is an effective mean for finding direct and indirect causes of association and permits a critical examination of specific forces acting to produce a given correlation and measure the relative importance of each causal factor.

The path analysis of pod yield correlated characters for pod yield per plant leads negative R^2. When characters drop one by one it became positive only after drop of shelling per cent i.e. 0.977 or after kernel yield per plant i.e. 0.862, residual effect in these were 0.15 and 0.37, respectively. This indicated that both kernel yield per plant and shelling per cent jointly distort the path coefficients as residual effect was negative in the presence of both the characters. Dropping of shelling per cent with kernel yield did not change the residual effect obtained after dropping of kernel yield (0.37). Likewise, dropping of harvest index also did not change the residual effect

obtained after dropping shelling per cent (0.15). This indicates dominance of kernel yield over shelling per cent and shelling per cent over harvest index. Unchanged residual effect obtained after dropping of harvest index with shelling per cent and low magnitude of direct effect suggest insignificant importance of these characters in pod yield. In all the sets of path analysis, the order of magnitude of direct and indirect effect was same but direction was changed in some cases.

On the basis of above discussion five characters were identified to work out the direct and indirect effects viz., days to flowering, total pods per plant, mature pods per plant, kernel yield per plant and 100-kernel weight. In these characters direct and indirect effect via kernel yield per plant, mature pods per plant and 100-kernel weight was higher. This indicated that significant correlation of these characters was mainly due to direct and indirect effect via kernel yield per plant, mature pods per plant and 100-kernel weight. Therefore, to improve yield selection can be exercised for kernel yield per plant, mature pods per plant and 100-kernel weight alongwith pod yield per plant. These results are in accordance with the findings of Reddy *et al.* (1986), Deshmukh *et al.* (1986), Vaddoria and Patel (1992), Francies and Ramalingam (1997), Bera and Das (2000) and Nagda *et al.* (2001b). One more conclusion can be drawn from the findings of this investigation that as far as possible avoid characters in path analysis which were calculated by using the dependent characters.

Economic heterotic crosses with non-significant SCA and involving atleast one general good combiner line are useful to select transgressive segregants in segregating generations but in present investigation no such cross could be identified for pod yield per plant. However, $L_1 \times T_2$ for kernel yield per plant and mature pods per plant, $L_1 \times T_1$ for mature pods per plant and $L_1 \times T_3$ for total pods per plant fulfilled the above criteria.

Therefore, these crosses may be used for identifying the transgressive segregants for these characters. Two crosses viz., L_{12} x T_1 and L_{10} x T_1 had significant SCA effects for pod yield per plant. As parents of these crosses were good general combiner, the economic heterosis was due to disperse dominance and complementary epistasis, therefore, these crosses also throw transgressive segregants in segregating generations. Since kernel yield per plant, mature pods and total pods per plant showed high positive correlation with pod yield per plant and negative correlation with days to flowering, therefore, it is possible to obtain transgressive segregants which may have high yield.

6. SUMMARY

The present investigation entitled "Combining ability for yield and yield components in groundnut (*Arachis hypogaea* L.)" was conducted during *kharif* 2001, at the Instructional Farm, College of Technology and Engineering, Udaipur. F_1s were generated by mating 12 lines with 3 testers in L x T fashion during *kharif* 2000. The 53 entries including 12 lines, 3 testers, 36 F_1s and two checks viz., SBXI and JL-24 were evaluated in randomized block design with three replications.

Observations were recorded on sixteen characters viz., days to flowering, height of main axis, primary branches per plant, haulm yield per plant, barren pegs per plant, total pods per plant, mature pods per plant, pod yield per plant, kernel yield per plant, harvest index, shelling per cent, 100-kernel weight, oil content, protein content, chlorophyll content and chlorophyll stability index. The data so obtained were subjected to analysis of variance, estimation of heterosis over mid-parent, better parent and best check, combining ability analysis, correlation and path coefficient analysis. The important findings of present investigation were as follows :

1. Analysis of variance revealed significant difference among genotypes for all the characters except chlorophyll stability index. In these characters difference among parents and hybrids was significant for all characters except primary branches per plant and chlorophyll content, respectively. In hybrids variance due to GCA of lines and SCA was significant for all the characters except SCA in shelling per cent. Whereas GCA of testers was significant in 12 characters.

2. Parental line L_3 exhibited highest mean for pod yield per plant and harvest index and line L_{12} had highest mean value for kernel yield per plant and shelling per cent. Tester T_2 exhibited highest number of total pods per and had minimum number of barren pegs per plant and was early to flower among all homozygous genotypes.

3. Significant heterosis was observed for all the characters in one or more crosses. Maximum heterotic crosses were for oil content. For pod yield per plant heterosis was significant in 21 crosses, out of which 19 crosses had positive heterosis. Heterobeltiosis was significant in eight crosses. Out of these, two hybrids viz., L_{12} x T_1 (23.58%) and L_{10} x T_1 (19.17%) recorded significant economic heterosis for pod yield. These hybrids also exhibited economic heterosis for kernel yield per plant. The crosses L_6 x T_3 and L_1 x T_2 also had economic heterosis for kernel yield per plant.

4. In the sum of squares of hybrids, the contribution of lines was maximum for all characters except total pods per plant and oil content where interaction of lines with tester contributed maximum. Contribution of tester was minimum for all the characters.

5. The ratio of $\Sigma SCA^2/\Sigma GCA^2$ was less than one for days to flowering, height of main axis, primary branches per plant, haulm yield per plant, pod yield per plant, kernel yield per plant, harvest index, shelling percent and 100-kernel weight whereas, for barren pegs per plant, total pods per plant, mature pods were plant, oil content and protein content this ratio was more than one.

6. The correlation between *per se* of lines and different hybrids of testers T_1, T_2 and T_3 was significant for 100-kernel weight, pod yield per plant, kernel yield per plant and harvest index. Correlation with

hybrids of T_1 and T_2 was significant for barren pegs per plant, days to flowering and height of main axis and with hybrids of T_2 and T_3 for haulm yield per plant whereas no such correlation was observed for oil content, shelling per cent and total pods per plant.

7. Estimates of GCA effects indicated that among lines L_1, L_3, L_6, L_{10} and L_{12} were good general combiner for pod yield per plant as well as kernel yield per plant. Among testers T_1 was good general combiner for total pods per plants, mature pods per plant and pod yield per plant, T_2 for protein and T_3 for shelling per cent and oil content.

8. Out of total 36 hybrids, 25 were good specific combiner for one or more characters except days to flowering where none of the cross was good general combiner. The hybrids $L_6 \times T_3$, $L_{10} \times T_1$, $L_8 \times T_3$ and $L_{12} \times T_3$ were good specific combiner for pod yield per plant as well as kernel yield per plant. These crosses were also good specific combiner for other characters.

Cross $L_{12} \times T_1$ and $L_{10} \times T_1$ having economic heterosis for pod yield and significant SCA involved both parents with good GCA effect.

9. Eight crosses possessed economic heterosis and involving atleast one good general combiner parent. All these crosses had significant SCA effects except $L_1 \times T_2$ for kernel yield per plant and mature pods per plant, $L_1 \times T_1$ for mature pods per plant and $L_1 \times T_3$ for total pods per plant.

10. The pod yield per plant was positively and significantly associated with kernel yield per plant, mature pods per plant, total pods per plant, harvest index, shelling per cent and 100-kernel weight while negatively correlated with days to flowering. Correlation among

positively correlated characters was also positive and their correlation with days to flowering was negative.

11. Path coefficient analysis for pod yield per plant indicated that characters kernel yield per plant, mature pods per plant, 100-kernel weight, total pods per plant and days to flowering governed 85 per cent variability of pod yield per plant. The most important characters among above were kernel yield per plant, mature pods per plant and 100-kernel weight.

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ABSTRACT

Combining Ability for Yield and Yield Components in Groundnut (*Arachis hypogaea* L.)

Vijay Singh Jat*
Research Scholar

Dr. B.R. Ranwah**
Major Advisor

The present investigation was undertaken with a view to estimate the extent of heterosis, heterobeltiosis, economic heterosis, combining ability, correlation and path coefficient in groundnut (*Arachis hypogaea* L.). Experimental material comprised of 12 lines, 3 testers (GG-2, TAG-24 and TG-17), their 36 hybrids and two checks viz., SB- XI and JL-24. The experiment was conducted at Instructional Farm of College of Technology and Engineering, Udaipur during *Kharif*, 2001 in randomized block design with three replications.

Observations were recorded on sixteen characters viz., days to flowering, height of main axis, primary branches per plant, haulm yield per plant, barren pegs per plant, total pods per plant, mature pods per plant, pod yield per plant, kernel yield per plant, harvest index, shelling per cent, 100-kernel weight, oil content, protein content, chlorophyll content and chlorophyll stability index. The plot means were subjected for analysis of above parameters.

The analysis of variance revealed significant difference among genotypes for all the characters except chlorophyll stability index. Among hybrids difference was also non significant for chlorophyll content. For all these characters desirable average heterosis was present except haulm yield per plant and barren pegs per plant.

For pod yield per plant out of 36 hybrids, 19 hybrids recorded significant positive heterosis and 8 recorded heterobeltiosis. These hybrids also exhibited significant heterobeltiosis for one or more yield component characters.

* *Research Scholar, Department of Plant Breeding and Genetics, R.C.A., Udaipur.*
** *Associate Professor, Department of Plant Breeding and Genetics, R.C.A., Udaipur.*

Economic heterosis was significant in eight crosses for one or more characters. Maximum economic heterosis was recorded for kernel yield per plant 37.22% (L_{12} x T_1) for pod yield per plant two crosses exhibited economic heterosis viz., L_{12} x T_1 and L_{10} x T_1.

The correlation between lines *per se* and their hybrids was significantly positive for most of the characters suggest presence of dominant genes in lines for these characters.

Estimates of GCA effects indicated that among lines L_1, L_3, L_6, L_{10} and L_{12} were good general combiner for pod as well as kernal yield per plant and their one or more componental traits. Among testers T_1 was good general combiner for pod yield per plant.

SCA effects for crosses revealed that five crosses for pod yield per plant and four crosses for kernel yield per plant showed significant SCA effects. The cross L_6 xL_3 was best specific combiner for pod yield per plant, kernel yield per plant, mature pods per plant and total pods per plant.

Crosses had significant economic heterosis also had significant SCA effect except L_1 xT_1 for mature pods per plant, L_1 x T_2 for kernel yield per plant and mature pods per plant and L_1xT_3 for total pods per plant. These three crosses recommended for handling in regregating generations to obtain the transgressive segregants. Apart from these, two crosses viz., L_{12}xT_1 and L_{10}xT_1 were having both good general combiner parent exhibited significant economic heterosis and significant SCA effect, also recommended for the purpose of obtaining the transgressive segregants for pod yield per plant as dispersed dominance is expected in these parents.

Pod yield per plant was positively associated with kernel yield per plant, mature pods per plant, total pods per plant, harvest index shelling per cent and 100-kernel weight while negatively correlated with days to flowering but, computation of residual effect using these characters was not possible. After dropping harvest index and shelling per cent, rest of the characters contributed 85 per cent variability of pod yield. Among these, the most important characters were kernel yield per plant, mature pods per plant and total pods per plant.

On the basis of this study, 5 crosses were identified for improvement of pod yield and its components through obtaining transgressive segregants in segregating generations.

मूंगफली (*अरैकिस हाइपोजिया* एल.) में उपज एवं उपज घटकों की संयोजन क्षमता

विजय सिंह जाट★
अनुसंधान कर्ता

डॉ. बी. आर. रणवा★★
मुख्य सलाहकार

अनुक्षेपण

वर्तमान अध्ययन मूंगफली (*अरैकिस हाइपोजिया* एल.) में संकर ओज की मात्रा, सार्थक संकर ओज, मानक किस्मों के ऊपर संकर ओज, संयोजन क्षमता, सह सम्बन्ध एवं पथ गुणांक का अध्ययन किया गया। परीक्षणात्मक सामग्री में 12 लाइन्स, 3 टैस्टरस् (जी जी - 2, टेग -24 एवं टी जी -17), इनके 36 संकरण और दो चैक अर्थात् एस बी - XI एवं जे एल -24 को सम्मिलित किया गया। यह प्रयोग तकनीकी एवं अभियांत्रिकी महाविद्यालय, उदयपुर के अनुसंधान फार्म पर खरीफ 2001 के दौरान तीन पुनरावृत्ति वाली यादृच्छिक खण्ड अभिकल्पना में लगाया गया।

सोलह गुण जैसे पुष्पन में लगें दिन, पादप ऊँचाई, प्रति पौधा प्राथमिक शाखाओं की संख्या, प्रतिपौधा पुआल उपज, प्रति पौधा निष्फल सुइयों की संख्या, प्रति पौधा कुल फलियों की संख्या, प्रति पौधा परिपक्व फलियां, प्रति पौधा फली उपज, प्रति पौधा गिरि उपज, कटाई सूचकांक, गिरि का प्रतिशत, 100-गिरियों का भार, तेल की मात्रा, प्रोटीन की मात्रा, हरित लवक की मात्रा और हरित लवक स्थिरता सूचकांक। प्रत्येक भू क्षेत्र औसत द्वारा उपरोक्त आनुवांशिक मापदण्ड ज्ञात किये गये।

प्रसरण विश्लेषण बताते हैं की हरितलवक स्थिरांक के अलावा सभी लक्षणों में जनकों एवं संकरों के लिए सार्थक अन्तर पाया गया। इनमें हरित लवक मात्रा के लिए संकरों में सार्थक अन्तर नहीं था। प्रति पौधा पुआल उपज एवं प्रति पौधा निष्फल सुइयों की संख्या के अलावा इन सभी लक्षणों हेतु में वांछित औसत संकर ओज पायी गयी।

संकर ओज अध्ययन के परिणाम बतातें है कि प्रति पौधा फली उपज के लिए 36 संकरों में से 19 संकरों में सार्थक धनात्मक संकर ओज तथा आठ संकरों में अति संकर ओज अंकित की गयी। इन आठ संकरों में दूसरे उपज से सम्बन्धित लक्षणों के लिए भी अति संकर ओज थी।

एक या अधिक लक्षणों के लिए सार्थक आर्थिक संकर ओज आठ संकरों में अंकित की गयी। अधिकतम आर्थिक संकर ओज 37.22 प्रतिशत ($L_{12} \times T_1$ में) प्रति पौधा गिरि उपज के लिए अंकित

★ अनुसंधानकर्ता, पादप प्रजनन एवं आनुवांशिकी विभाग, राजस्थान कृषि महाविद्यालय, उदयपुर।
★★ सह-आचार्य, पादप प्रजनन एवं आनुवांशिकी विभाग, राजस्थान कृषि महाविद्यालय, उदयपुर।

की गयी। प्रति पौधा फली उपज के लिए दो संकरों ($L_{10} \times T_1$ और $L_{12} \times T_1$ में) में आर्थिक संकर ओज थी।

लगभग सभी लक्षणों के लिए लाइन्स एवं उनके संकरों के मध्य सार्थक धनात्मक सह-सम्बन्ध पाया गया जो कि इन लक्षणों के लिए लाइन्स में प्रभावित जीनों की उपस्थिति दर्शाती है।

सामान्य संयोजिता का आकलन दर्शाता है कि लाइन्स L_1, L_3, L_6, L_{10} एवं L_{12} प्रति पौधा फली एवं गिरि उपज तथा एक या एक से अधिक घटक लक्षणों के लिए अच्छे संयोजक है। टेस्टरस् में T_1 प्रति पौधा फली उपज के लिए अच्छा सामान्य संयोजक पाया गया। संकरों में से 5 ने प्रति पौधा फली उपज तथा 4 ने प्रति पौधा गिरि उपज के लिए विशिष्ट संयोजिता दर्शाई। संकर $L_6 \times T_3$ को प्रति पौधा फली उपज, प्रति पौधा कुल फलियों की संख्या के लिए अति विशिष्ट संयोजक पाया गया। प्रति पौधा परिपक्व फलियों के लिए $L_1 \times T_1$, प्रति पौधा गिरि उपज एवं प्रति पौधा भरी हुयी फलियों के लिए $L_1 \times T_2$ तथा प्रति पौधा कुल फलियों के लिए$L_1 \times T_3$ के अलावा सभी संकरों ने सार्थक आर्थिक संकर ओज व विशिष्ट संयोजिता दर्शायी।

तीन संकरों का अतिक्रायी विसंयोजना प्राप्त करने के लिए चयन किया गयाा इन सबके अलावा, प्रति पौधा फली उपज के लिए दो संकरों अर्थात् $L_{12} \times T_1$ एवं $L_{10} \times T_1$ जिनके दोनों जनक अच्छे सामान्य संयोजक थे तथा जिन्होंने आर्थिक सार्थक संकर ओज एवं सार्थक विशिष्ट संयोजिता दर्शाई, उनका भी अतिक्रायी विसंयोजन प्राप्त करने के लिए चयन किया गया।

प्रति पौधा फली उपज का प्रति पौधा गिरि उपज, प्रति पौधा भरी हुयी फलियों की संख्या, प्रति पौधा कुल फलियों की संख्या, कटाई सूचकांक, गिरि का प्रतिशत एवं 100- गिरि वजन के साथ धनात्मक सह-संम्बन्ध जबकि पुष्पन में लगें दिनों के साथ में ऋणात्मक सह-सम्बन्ध पाया गया लेकिन इन लक्षणों का फली की उपज में कुल योगदान ज्ञात करना सम्भव नहां था। अतः एक-एक लक्षण कम करके इनका पथ विचलन ज्ञात किया गया। जब गिरि प्रतिशतता एवं कटाई सुचकांक को छोड़कर पथ विचलन ज्ञात किया गया तो इन गुणों ने 85 प्रतिशत उपज की विभिन्नता को नियंत्रित करना दर्शाया। इन लक्षणों में मुख्य रूप से प्रभावित करने वाले कारक प्रति पौधा गिरि उपज, प्रति पौधा परिपक्व कलियां एवं प्रति प्रौधा कुल फलियों की संख्या थे।

इस अध्ययन के आधार पर 5 संकरों का फली उपज एवं इसके घटकों का अतिक्रायी विसंयोजन के द्वारा विसंयोजन पीढीयों में सुधार के लिए चयन किया गया।

APPENDIX-I

Meterological Observations (Weekly averages) during Course of Investigation (June 2001 to October 2001)

Standard week no.	Duration	Temperature (°C)		R.H.		Wind velocity 24 hrs. km/hr	Sunshine (h/day)	Rainfall (week total in mm)	Evaporation (week total in mm)
		Max.	Min.	Morn.	Even.				
23	June 04-June 10	36.2	25.3	71	39	7.4	8.9	41.0	9.4
24	June 11-June 17	33.5	23.9	85	59	4.9	4.5	78.5	4.3
25	June 18-June 24	32.2	25.1	75	56	10.1	7.0	0.0	6.6
26	June 25-July 01	32.0	25.2	74	57	8.9	6.7	0.8	5.8
27	July 02-July 08	28.3	23.5	91	82	3.7	2.5	83.0	2.9
28	July 09-July 15	28.3	23.6	87	79	5.2	1.7	148.4	3.9
29	July 16-July 22	27.7	23.6	88	79	5.4	1.1	9.6	2.4
30	July 23-July 29	28.6	23.6	88	75	4.6	1.8	8.8	2.5
31	July 30-Aug. 05	29.2	22.9	87	71	3.3	4.1	4.2	2.9
32	Aug. 06-Aug. 12	31.0	23.1	92	78	2.0	4.8	43.2	3.1
33	Aug. 13-Aug. 19	29.1	23.2	90	84	2.7	2.8	86.0	2.9
34	Aug. 20-Aug. 26	29.5	21.5	90	68	3.0	5.4	0.3	3.0
35	Aug. 27-Sept. 02	29.2	22.1	81	65	6.1	6.7	0.0	4.4
36	Sept.03-Sept. 09	31.1	20.5	88	58	4.3	8.7	0.0	4.6
37	Sept.10-Sept. 16	37.9	20.1	61	57	3.2	6.1	0.0	4.1
38	Sept.17-Sept.23	34.3	20.7	80	54	2.7	8.7	3.8	4.3
39	Sept.24-Sept.30	36.5	19.3	70	27	2.1	7.9	0.0	5.0
40	Oct.01-Oct. 07	33.6	20.0	84	41	2.7	7.2	0.0	3.9
41	Oct.08-Oct. 14	33.7	21.6	85	48	3.2	6.3	0.0	4.2
42	Oct.15-Oct.21	34.0	13.1	75	21	1.9	9.8	0.0	4.6
43	Oct.22-Oct.28	34.9	12.7	71	15	2.1	10.0	0.0	4.6
44	Oct.29-Nov.04	34.4	13.5	73	24	2.4	9.8	0.0	4.3

Source : Meterological observatory Instructional Farm, College of Technology and Engineering, Udaipur.

APPENDIX-II

Determination of Oil Content in Groundnut Seeds (Specific Gravity Method)

Principles :

Inverse relation-ship between the oil content and the specific gravity of seeds can be used for determination of oil content of groundnut kernels (Misra, 1998). This relationship has now been defined in form of binomial equation as follows :

Oil (percentage) = 239.7 - (176.8 × specific gravity of seed).

Procedure :

A. Determination of specific gravity of kerosene (SGK) : Place 100 ml volumetric flask on the pan of balance and tare it to 0.000 g. Remove the flask and fill it with kerosene up to the graduation mark. Completely wipe out any kerosene adhering to exterior of the volumetric flask. Replace the flask on the balance. Record the weight of 100 ml kerosene in gram and obtain the specific gravity of kerosene as follows :

$$SKG = \frac{weight\ of\ 100\ ml\ kerosene}{100}$$

Repeat the exercise three times and take the average of these SKG values. This value of SKG is used as a constant in calculating the oil content of samples. Work out SKG for each lot of kerosene. The specific gravity of commercial kerosene ranges from 0.780 to 0.810.

B. Determination of specific gravity (SGS) of groundnut samples:

Step 1 : Split seeds into halves by separating the two cotyledons with germ attached to any one. Don't attempt to remove the testa. Splitting of seeds into halves is necessary to eliminate the interference caused by the gas filled in the lumen of seeds. These seed halves will be referred as sample here after.

Step 2 : Place about 10 g of sample on the balance and record its exact weight (WS).

Step 3 : Place 100 ml volumetric flask filled to the mark with kerosene on the balance and tare it.

Step 4 : Remove the volumetric flask from the balance. Transfer the weighed (WS) sample in the flask. Free the air bubbles sticking to the sample. Remove the kerosene displaced by the sample with pipette or a dropper to return the meniscus to 100 ml mark. Wipe out the kerosene, if any, sticking to the exterior of flask.

Step 5 : Weigh the flask containing the sample record this weight as WD.

Step 6 :

$$\textit{The volume of WS } (V) = \frac{WS - WD}{SGK}, \quad \textit{and}$$

Specific gravity of sample (SGS) is given by :

$$SGS = WS/V.$$

The oil content of the sample is given by :

$$\text{Oil (percent)} = 239.7 - (176.8 \times SGS)$$

A spread sheet can be used to facilitate step wise calculation by using an ordinary calculator.

Spreadsheet for calculating the oil content of groundnut samples

Date : _____ Season : _____

Location : _____

Specific Gravity of kerosene SGK :_____

S.N.	Weight of sample (WS)	Weight of sample plus kerosene (WD)	Weight of kerosene displaced by sample	Volume of sample	Specific gravity of sample	176.8 × Specific gravity of sample	Oil content of sample
A	B	C	D=B-C	E=D/SGK	F=B/E	G=176.8 × F	H=239.7-G
1.							
2.							
3.							

APPENDIX-III

Estimation of Crude Protein by Micro-Kjeldhals Method Using Nessler's Reagent

Principles:

Nessler's reagent is an aqueous solution of potassium mercuric iodide ($KI.HGI_2$). It react with NH_3 (or NH_4-salts) to give reddish brown colour of precipitate. In the presence of sodium silicate the coloured precipitate are rapidly and completely removed from solution leaving behind a clear, nonturbid coloured solution. The colour developed remains stable upto 15 heat room temperature (20-45°C), its intensity is proportional to the united concentration of NH_3 nitrogen by Nesslerization. The colour can be read at 440-650 nm but sensitivity in more at shorter wave length.

Procedure :

A. Digestion :

1. Grind the seed material and weight 0.1 g of sample and put in a dry 30 ml. Kjeldhals flask.

2. Add 2 ml. of concentrated H_2SO_4 (Analar) and digest on heater for 1.30 h (a short funnel may be used as a reflux)

3. To this add 0.5 ml H_2O_2 (30%) with alternate heating and cooling till the colour disappears. Heat further until H_2O_2 fumes escape.

4. Transfer the contents of Kjeldhal flask to 100 ml. volumetric flask and make volume.

B. Colour Development :

1. Take 5 ml aliquat in 50 ml volumetric flask, add 2 ml and 1 ml of 10 per cent solution of NaOH and 10 per cent solution of sodium silicate, respectively. Add 1.6 ml Nesslers reagent and finally make volume with distilled water. After 10 minutes absorbance may be recorded.

2. Run a control without sample by the same procedure.

3. Adjust - Colorimeter using control and take absorbance (OD) reading at 540 nm. In this study, calorimetric reading were taken at 630 nm.

C. Standard curve :

1. Dissolve 0.1179 g of ammonium sulphate in distilled water and make the volume to 1 litre (25 ppm NH_3-N solution).

2. Pipette out 1, 2, 3, 4, 5, 10, 15 and 20 ml. (or 0.5, 1.0, 1.5, 2.0, 2.5, 5.0, 7.5 and 10 ppm) of this solution in 50 ml. Volumetric flask.

3. Develop colour by procedure given above and read absorbance at same wave length.

4. Draw a standard graph between ppm. NH_3-N and absorbance valve.

D. Estimation of crude protein :

1. Determine the N-content of sample using the standard curve. The crude protein content is calculated by multiplying the N content with 6.25.

APPENDIX-IV

Estimation of Chlorophyll Content by DMF Method

1. In the morning hours the leaf samples was brought in ice box from the field.

2. One piece of leaf was weighed (W_1) on electronic balance and put in the oven. After 72 hours dry weight (W_2) of leaf sample was recorded.

3. A sample of 0.059 of above fresh leaf was weighed and emerged in 10 ml N, N-dimethyl formamide (DMF) and stored in dark for 24 hours.

4. Optical density (OD) readings of extract was recorded at 663 A° nm and 645 A° nm on spectrophotometer.

5. The chlorophyll content mg/g of dry tissue was calculated as follows:

$$Chlorophyll\ content\ (mg/g) = \frac{10 \times 8.02 \times (663\ A^{o}) + 20.20 \times (645\ A^{o}\ nm)}{1000 \times 0.05}$$

6. For chlorophyll stability index, one more sample of 0.05 g of fresh leaf was run under heat bath for one hour and chlorophyll was estimated as producer given above.

APPENDIX-V

Path Analysis for Different Sets of Characters in Groundnut

V-A

	1	6	7	9	10	11	12	r
1	-0.0375	-0.0019	0.0117	-0.6946	-0.0009	0.1206	0.0091	-0.5935
6	0.0161	0.0044	-0.0156	0.7516	0.0007	-0.0979	-0.0035	0.6558
7	0.0202	0.0031	-0.0217	0.8310	0.0009	-0.0829	-0.0029	0.7475
9	0.0229	0.0029	-0.0159	1.1376	0.0011	-0.1513	-0.0093	0.9880
10	0.0220	0.0020	-0.0132	0.8452	0.0015	-0.1065	-0.0073	0.7438
11	0.0195	0.0018	-0.0078	0.7418	0.0007	-0.2320	-0.0070	0.5170
12	0.0243	0.0011	-0.0045	0.7587	0.0008	-0.1163	-0.0140	0.6500

Res. Effect : R Square is Negative i.e. -0.00

V-B

	1	6	7	10	11	12	r
1	0.2277	-0.0583	-0.2819	-0.1215	-0.0148	-0.3447	-0.5935
6	-0.0975	0.1361	0.3762	0.0952	0.0120	0.1337	0.6558
7	-0.1222	0.0976	0.5250	0.1259	0.0102	0.1112	0.7475
10	-0.1334	0.0625	0.3185	0.2074	0.0131	0.2757	0.7438
11	-0.1183	0.0574	0.1876	0.0952	0.0285	0.2666	0.5170
12	-0.1476	0.0342	0.1098	0.1075	0.0143	0.5317	0.6500

Res. Effect: 0.37

V-C

	1	6	7	9	10	12	r
1	0.0540	0.0070	-0.0553	-0.5540	-0.0112	-0.0341	-0.5935
6	-0.0231	-0.0163	0.0738	0.5995	0.0087	0.0132	0.6558
7	-0.0290	-0.0117	0.1029	0.6627	0.0116	0.0110	0.7475
9	-0.0329	-0.0108	0.0752	0.9073	0.0142	0.0351	0.9880
10	-0.0316	-0.0075	0.0624	0.6741	0.0191	0.0273	0.7438
12	-0.0350	-0.0041	0.0215	0.6051	0.0099	0.0526	0.6500

Res. Effect: 0.15

Where,

1. Days to flowering 6. Total pods per plant 7. Mature pods per plant
9. Kernel yield per plant 10. Harvest index 11. Shelling per cent
12. 100-kernel weight r Correlation coefficient of pod yield with other characters

Contd..

V-D

	1	6	7	10	12	r
1	0.2217	-0.0616	-0.2807	-0.1238	-0.3492	-0.5935
6	-0.0950	0.1437	0.3746	0.0969	0.1354	0.6558
7	-0.1190	0.1030	0.5227	0.1282	0.1127	0.7475
10	-0.1299	0.0659	0.3172	0.2113	0.2793	0.7438
12	-0.1437	0.0361	0.1093	0.1095	0.5387	0.6500

Res. Effect: 0.37

V-E

	1	6	7	11	12	r
1	0.2120	-0.0530	-0.3381	-0.0256	-0.3889	-0.5935
6	-0.0908	0.1237	0.4513	0.0207	0.1508	0.6558
7	-0.1138	0.0887	0.6297	0.0176	0.1255	0.7475
11	-0.1102	0.0522	0.2250	0.0492	0.3008	0.5170
12	-0.1374	0.0311	0.1317	0.0247	0.6000	0.6500

Res. Effect: 0.40

V-F

	1	6	7	12	r
1	0.2010	-0.0585	-0.3378	-0.3983	-0.5935
6	-0.0861	0.1365	0.4509	0.1545	0.6558
7	-0.1079	0.0978	0.6292	0.1285	0.7475
12	-0.1303	0.0343	0.1316	0.6144	0.6500

Res. Effect: 0.40

Where,

1. Days to flowering 6. Total pods per plant 7. Mature pods per plant
9. Kernel yield per plant 10. Harvest index 11. Shelling per cent
12. 100-kernel weight r Correlation coefficient of pod yield with other characters