COMBINING ABILITY FOR DROUGHT TOLERANCE AND YIELD IN BLACKGRAM

(*Vigna mungo* (L.) Hepper)

By

ROY ISAAC VARGHESE

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DECLARATION

I hereby declare that this thesis entitled "**Combining ability for drought tolerance and yield in blackgram (*Vigna mungo* (L.) Hepper)**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

Vellayani,
4-12-1997.

ROY ISAAC VARGHESE.

CERTIFICATE

Certified that this thesis entitled "**Combining ability for drought tolerance and yield in blackgram (*Vigna mungo* (L.) Hepper)**" is a record of research work done independently by Mr. ROY ISAAC VARGHESE. (95-11-30) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

Dr. K. M. Abdul Khader
Associate Professor
Plant Breeding and Genetics
College of Agriculture
Vellayani

Vellayani
4-12-97

APPROVED BY

CHAIRMAN

Dr. K. M. ABDUL KHADER

MEMBERS

Dr. R. GOPIMONY

Dr. S. G. SREEKUMAR

Dr. VIJAYA RAGHAVAKUMAR

EXTERNAL EXAMINER

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INTRODUCTION

INTRODUCTION

Pulses are important constituents of the Indian diet and supply a major part of the protein requirement. Pulse crop, besides being rich in protein and some of the essential amino acids, enrich the soil through symbiotic nitrogen fixation. Blackgram (urd) is one of the important pulse crop grown through out India. It is consumed in the form of 'dal' or parched. It is the chief constituent of papad. It is used for making 'dosa' or 'iddli'. It is also used in the preparation of 'halwa'.

The production of blackgram is very low in Kerala even though it forms a major part in our diet. The major part of grain legume requirement is met from urdbean. The percapita availability of grain legume in India is only 60 g per day. (Jeswani, 1986) as against 80 g per day recommended by FAO and WHO. So the low productivity emphasises the need for increasing the production of pulses in India and also in our state.

The production of pulses has not gone up because they are cultivated in areas totally devoid of irrigation facilities. Only 9.5 per cent of area under gram is irrigated. The late onset of monsoon in 1995 has resulted in a reduction of about 15 percentage area covered under kharif pulses in the year. Production fluctuates from year to year depending on the behaviour of the monsoon. Having fluctuated between 10.9 million tonnes in 1987-88 to

12.8 million tonnes in 1992-93 pulses production was 13.1 million tonnes in 1993-94. Production in 1994-95 was 13.8 million tonnes as against the target of 15.5 million tonnes (Economic Times., 1995).

Production of pulses in India during the year 1994-95 in kharif and rabi season was 5.407 million tonnes and 8.471 million tonnes respectively and in Kerala it was 3000 tonnes and 16000 tonnes respectively (Sharma, 1995). In Kerala the grain legumes are mainly grown in summer rice fallows and irrigation facilities are very low. This situation calls for development of drought tolerant varieties with high yield potential in blackgram.

Different varieties respond differently to drought and in an earlier study conducted in the Department of Plant breeding, Kerala Agricultural University, the varieties, TAU 2, PDU 5, CoBG 302, PDU 101 and T 9 have been identified as drought tolerant (Rani, 1989). The studies on combining ability and gene action are prerequisites in formulating efficient breeding strategies and choice of suitable parents for crosses in breeding programmes. The present study was taken up with a view to obtain information on general and specific combining ability and type of gene action involved in the inheritance of drought tolerance, grain yield and its components for improving the yield potential under moisture stress conditions.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

In crop improvement programme both additive and non additive gene action play an important role in selection of parents with respect to quantitative traits which can well be estimated through line x tester crosses. The present study was taken with an objective to study the nature and magnitude of gene action governing yield and drought tolerance characters in blackgram through combining ability analysis. A review of the available literature on important pulse crops particularly blackgram is given here under.

2.1 Duration up to 50 per cent flowering

In a diallel analysis involving seven soybean varieties specific combining ability (sca) variance was found to be significant in the F_2 generation. The general combining ability (gca) variance was higher than that of sca variance in F_1 and F_2 generations (Srivatsava *et al.*, 1977).

While analysing the combining ability in mungbean in a diallel cross involving eight varieties Deshmukh and Manjare, (1980) found highly significant variances due to gca for days to flowering. They reported non additive gene action for the character.

Durong (1980) studied yield and related characters using 8 x 8 diallel cross in soybean and reported involvement of additive gene action.

Dhillon and Chahal (1981) showed predominance of additive genetic variance for number of days to flower in garden pea in a 6 x 6 diallel cross.

Combining ability analysis of ten diverse cultivars of pigeon pea indicated the predominance of additive gene action for days to first flower opening as reported by Venkateswarlu and Singh (1981a).

Combining ability studies through 10 x 10 diallel cross in pea by Dubey and Lal (1983) showed significant gca and sca variance for duration up to flowering. In general, additive genetic variance was found to be higher than dominance variance for this character.

Salimath and Bahl (1985) showed from a line x tester analysis in chickpea the importance of gca and sca variance for days to flower. The variance due to gca was higher than the variance due to sca indicating the importance of additive gene action for the character.

Significant gca and sca variances were reported by Wilson *et al.* (1985) for days to flowering in the analysis of the diallel cross involving five varieties of greengram and suggested the existence of both additive and non additive gene action. The variance due to gca was much higher than that due to sca indicating the predominance of additive gene action.

Patil and Bhapkar (1986) reported additive gene effects alone for days to flowering studying yield and related characters using parents and F_1 of half diallel cross in cowpea.

Combining ability for yield and its components was studied in the F_2 from a 5 x 5 diallel cross of lablab bean by Singh *et al.* (1986) and reported that gca variance was higher for days to flowering, indicating the presence of additive gene action.

In a line x tester analysis by Mandal and Bhal (1987) in chickpea showed significant difference in days to flowering. The gca effect was not significant for the trait indicating non additive gene action.

Katiyar *et al.* (1987) in a line x tester analysis in pea observed the predominance non additive gene action for days to flower. Katiyar *et al.* (1988) in a study with six chick pea genotype and their F_1 hybrids showed significant differences for gca and sca variances for days to flower and reported the action of additive and non additive gene effects. Predominance of additive gene action was indicated for this character.

In a 5 x 5 diallel analysis in pigeon pea Cheralu *et al.* (1989) observed high gca for days to flowering.

Half diallel analysis of seven short duration pigeon pea lines were evaluated in the F_1 and F_2 generations by Saxena *et al.* (1989). The result indicated the predominance of gca variance for the character.

Diallel analysis of six cultivars of cowpea indicated significant gca and sca variances and importance of additive gene action (Rejatha, 1992).

A line x tester analysis of cowpea varieties involving five lines and three testers by Kumar (1993) showed the presence of additive and non additive gene action with predominance of non additive gene action for duration up to flowering.

In a line x tester analysis involving five lines and four testers in mungbean, Naidu and Satyanarayana (1993) reported that additive genetic variance was important for days to 50 per cent flowering.

In a combing ability analysis of 4 lines x 3 tester cross on cowpea by Thiyagarajan *et al.* (1993) variance due to gca and sca showed that gene action was predominantly non additive for days to 50 percent flowery.

Combining ability analysis of eight varieties of chick pea and their 28 F_1 s by Jahagirdar *et al.* (1994) showed that non additive effects were predominant for days to 50% flowering.

2.2 Duration up to maturity

A diallel cross involving eight mungbean varieties by Deshmukh and Manjare (1980) showed that the variances due to gca and sca were highly significant for days to maturity and non additive gene action was important for this character.

Durong (1980) studied combing ability using a 8 x 8 diallel cross of soybean and reported additive gene action for the trait.

In a half diallel cross in eight cowpea varieties Chauhan and Joshi (1981) revealed that both gca and sca variance were important for days upto maturity and gca variance was higher than sca variance suggesting additive gene action for the trait.

Combing ability analysis in six parental diallel cross in urd bean by Sandhu *et al.* (1981) revealed that both additive and non additive effects were important for days to maturity and that non additive gene action was preponderant for all characters except days to maturity.

Significant gca and sca variances were reported by Wilson *et al.* (1985) for days to maturity in an analysis of a diallel cross among five greengram varieties. They found that the variance due to gca was much higher than that due to sca and reported the existence of additive gene action.

Salimath and Bahl (1985) conducted a line x tester analysis in chick pea with five males and nine females and reported that sca variance was important for days to maturity. They also reported the importance of non additive variance for days to maturity.

Patil and Bhapkar (1986) studied yeild and related characters from the parents and F_1 of a half diallel cross of cowpea and reported additive gene action.

Combing ability analysis of thirty nine hybrids between three lines and thirteen testers by Patel *et al.* (1987) in pigeonpea revealed significant role of additive and non additive gene action with preponderance of non additive gene action for duration of the crop.

Singh *et al.* (1987) studied ten diverse blackgram cultivars for combining ability and reported highly significant gca and sca variances in F_1 and F_2 generations. The estimates of variance due to sca was greater than that due to gca for days to maturity, indicating the predominance of non-additive gene action.

Yadavendra and Sudhirkumar (1987) analysed the combining ability for days to maturity with eight chickpea lines and their 28 F_1 in a diallel analysis showed the importance of additive gene action for the character.

From a combining ability analysis involving nine diverse parents and their 36 F_1 crosses in pigeonpea, Mehetre *et al.* (1988) reported that both additive and nonadditive gene effects were important for days to maturity and that additive gene effect was predominant for the character.

Twelve hybrids from three male and four female parents of cowpea were evaluated for combining ability in two seasons for yield and yield components by Thiyagarajan (1992) and reported the preponderance of additive variance.

Combining ability analysis through a line x tester analysis by Kumar (1993) showed the presence of both gca and sca variance, with preponderance of non additive gene action for the character duration up to maturity in cowpea.

In cowpea line x tester crosses were made involving 4 lines and 3 testers by Thiyagarajan *et al.* (1993) variance due to gca and sca showed that gene action was predominantly non additive for days to maturity.

Combining ability analysis of eight varieties of chickpea by Jahagirdar *et al.* (1994) showed that gca variance was lower than sca and non additive effects were predominant for duration up to maturity.

2.3 Leaf Area Index

A ten parent half diallel cross of mungbean was conducted by Candra and Nijhawan (1979) to estimate the combining ability for leaf area index and proposed the presence of non additive gene effect.

Deshmukh and Bhapkar (1982) analysed a half diallel cross involving nine parents in chickpea and reported that leaf area index was predominantly governed by non additive gene effect.

Genetic architecture, combining ability and heterosis for certain physiological parameter in sesamum were studied by Reddy and Haripriya (1990) in a 9 x 9 diallel set of cross and reported that both additive and non additive gene action were evident for leaf area index.

Kumar (1993) in a combining ability analysis involving 5 lines x 3 testers in cowpea reported the presence of additive gene action for leaf area index.

In a line x tester analysis in greengram involving five lines and three testers by Sreekumar (1993) reported the presence of non additive gene action.

2.4 Leaf hairiness

In an experiment on spring durum wheat Tsapaikin and Krupnov (1988) crossed donors of leaf hairiness *Triticum dicoccum* K47795 and *Triticum durum* varieties were back crossed with the recurrent parents in a diallel crossing scheme. They found that leaf hairs were controlled by Hl genes with additive and dominance effect.

2.5 Stomata per microscopic field

Miskin *et al.* (1972) observed that in barley stomatal resistance would be advantageous in water economy and drought resistance.

Rani (1989) analysed 20 black gram genotypes for tolerance to drought based on number of stomata per microscopic field and other characters and found that selection index based on important drought parameters was effective than direct selection.

2.6 Root shoot ratio

Rani (1989) reported that plants with lower root shoot ratio was better adapted to drought in an analysis for drought tolerance of 20 black gram genotypes.

In a line x tester analysis in greengram, Sreekumar (1993) observed the presence of both gca and sca variances and predominance of non additive gene action for root shoot ratio.

2.7 Spread of root at harvest

Nanga and Saxena (1986) while analysing the combining ability for root and related traits in pearlmillet from a line x tester cross involving four lines and two testers revealed the importance of non additive gene action for root length.

Islam *et al.* (1987) in a study of eight mungbean genotypes and their twenty eight F_1 s in a half diallel cross revealed significant additive and non additive genetic variances for seedling root length and yield, but additive gene action was more important for root length.

In a line x tester cross of *Vigna radiata* involving 4 lines x 5 testers Rosaiah *et al.* (1994) found that sca variance were higher than gca variance for root length indicating nonadditive gene action.

2.8 Proline Content

Kumar (1993) in cowpea found that sca alone was significant in a line x tester cross and the ratio of additive to dominance effect less than unity for proline content suggesting non additive gene action.

In a line x tester analysis involving three lines and five testers in greengram Sreekumar (1993) found that both additive and non additive gene action were significant for proline content.

2.9 Plant height

In black gram Sagar and Chandra (1977) in a 6 x 6 diallel analysis suggested that variance due to gca was much larger than sca variance indicating the predominance of additive gene action for plant height.

In a line x tester analysis Rajarathinam and Ratnaswamy (1990) reported that variance due to sca was of greater magnitude than gca in black gram suggesting non additive gene action for plant height.

Naidu and Satyanarayana (1993) in a combining ability analysis involving four lines and five testers of mungbean found that non additive gene action was mainly responsible for plant height. High yielding heterotic crosses were obtained for parents with high gca.

2.10 Number of branches per plant

In a line x tester analysis involving four lines and five testers Naidu and Satyanarayana (1993) observed that non additive gene action was mainly responsible for number of branches per plant in mungbean.

In a combining ability analysis involving 4 lines x 3 testers in cowpea by Thiyagarajan *et al.* (1993), variance due to sca was greater than gca and nonadditive gene action was predominant for number of branches per plant.

In an evaluation of eight varieties on *Cicer arietinum* and their 28 F_1 s by Jahagirdhar *et al.* (1994) both additive and non additive gene effects appeared important for plant height and number of primary branches per plant; gca variance was lower than sca variance for these character.

Five lines and three pollen parents of *cicer areitinum* and their 15 F_1 s were evaluated by Mishra and Yadav (1994) and estimates of variance due to gca and sca suggested significance of non additive type of gene action for number of branches per plant.

In a combining ability analysis in pea (*Pisum sativum*) Singh *et al.* (1994) analysed ten parents 45 F_1 s' and 45 F_2 s' during 1985-86 and gca and sca variances were found to be significant. Additive genetic variance appeared to be predominant for the character number of branches per plant. The gca variance was higher than sca variance.

2.11 Pod characters

In a study of 6 x 6 diallel cross of blackgram conducted by Sagar and Chandra (1977) revealed that the magnitude of sca variance was very high suggesting the predominance of non additive gene action for number of pods per plant and the variance due to gca and sca were significant.

Diallel analysis for yield components in chick pea showed highly significant variances due to gca and sca for number of pods per plant and seeds per pod. Estimates of variance due to sca were much higher than the estimates of variance due to gca indicating preponderance of nonadditive gene action (Pande *et al.*, 1979).

Deshmukh and Manjare (1980) while estimating combining ability in greengram in a diallel cross observed significant variances due to gca and sca for number of pods per plant and number of seeds per pod and reported non additive gene action.

Durong (1980) studied combining ability using a 8 x 8 diallel cross of soybean and reported importance of both additive and nonadditive gene action.

The inheritance study of seed yield components in ricebean using a seven parent diallel cross excluding reciprocals was done by Das and Dana (1981) and reported the importance of dominant gene action for number of seeds per pod.

In a half diallel cross of eight cowpea varieties, along with their parents by Chauhan and Joshi (1981) both gca and sca variances were important for number of pods per plant and seeds per pod and there was a predominance of additive gene action for these traits.

Combining ability analysis using a complete set of six parent diallel cross of garden pea for yield components showed predominance of nonadditive gene action for number of seeds per pod and pods per plant (Dhillon and Chahal, 1981).

Venkateswarlu and Singh (1981a) while analysing the combining ability of peas in a diallel cross involving ten cultivars found importance of both gca and sca and predominant role of additive gene effects for the characters seeds per pod and pods per plants.

Combining ability studies through 10 x 10 diallel analysis in pea by Dubey and Lal (1983) showed that general and specific combining ability variances were significant and additive genetic variance found higher than dominance variance for number of pods per plant and number of seeds per pod. Singh *et al.* (1983) estimated combining ability using a 8 x 3 line x tester cross in pigeonpea and reported that both additive and nonadditive components were important with predominant role of additive component for number of pods per plant.

Yield and yield related characters were investigated in six cowpea genotypes and their fifteen possible non reciprocal single crosses by Zaveri *et al.* (1983) and reported significance of both gca and sca variance and predominance of nonadditive genetic variance.

Information on combining ability was derived from a diallel cross of five greengram varieties by Wilson *et al.* (1985). They have suggested the existence of both additive and non additive gene action for number of seeds per pod and pods per plant with a predominance of additive gene action.

Significant gca and sca variances for number of pods per plant was reported by Chowdhury (1986) in an analysis of half diallel cross with eight greengram varieties and reported the importance of both additive and nonadditive gene action.

Singh *et al.* (1987) in the study of combining ability with 45 F_3 progenies generated from 10 x 10 diallel cross in pea revealed that both additive and nonadditive gene effects were significant for the expression of number of pods per plant.

Combining ability analysis with ten soybean lines and their F_1 hybrids for number of pods per plant revealed that both additive and nonadditive genetic variances were important for this character (Sharma and Nishisharma, 1988).

Saxena and Sharma (1989) estimated combining ability in mungbean in a 8 x 8 diallel analysis and reported that both gca and sca mean squares were significant in F_1 and F_2 for number of seeds per pod. The gca effect was higher than sca indicating additive gene action for number of seeds per pod.

The importance of both additive and non additive gene actions for number of pods per plant and seeds per pod was observed by Natarajan *et al.*, (1990) in a 7 x 7 diallel cross in greengram.

In a line x tester analysis in black gram by Rajarathinam and Rathnaswamy (1990) revealed that the variance due to sca was greater than gca for number of pods per plant indicating the preponderance of non additive gene action.

In cowpea, combining ability was estimated in a diallel cross by Thyagarajan *et al.* (1990). They reported the importance of both additive and non additive gene effects for number of pods per plant and nonadditive effects were predominant.

Twelve hybrids from three males and four female parents of cowpea were evaluated for combining ability in two seasons for yield and yield components by Thiyagarajan (1992) and reported preponderance of additive variance for seed per pod and pods per plant.

In a combing ability analysis involving 4 lines and 5 testers of mungbean by Naidu and Satyanarayana (1993) reported that non additive gene action was mainly responsible for the character seeds per pod.

Singh and Singh (1993) in the diallel analysis involving 5 varieties of Lentil found that sca variance is more than gca and additive gene action had a greater role for seeds per pod.

Significant sca variance for number of pods per plant was reported by Mishra and Yadav (1994) in a line x tester analysis using 5 lines x 3 testers in *Cicer arietinum* indicating additive gene action.

2.12 Grain yield per plant

Pande *et al.* (1979) in a diallel analysis for yield and yield components in bengalgram revealed that variance due to general and specific combining ability were highly significant for yield per plant indicating that genes having additive and dominant effects were influencing the character. It was also reported that non additive effect was more important for seed yield per plant.

A diallel cross involving eight mungbean varieties was analysed by Deshmukh and Manjare (1980) for combining ability. The variances due to gca and sca were highly significant for grain yield per plant. Non additive gene action was reported to be more important for this character.

Durong (1980) studied combining ability using a 8 x 8 diallel cross of soybean and reported importance of both additive and nonadditive gene action.

A complete set of six parent diallel cross in garden pea was evaluated by Dhillon and Chahal (1981) and reported predominance of non additive gene action for yield per plant.

Venkateswarlu and Singh (1981b) while analysing the combining ability in peas in a diallel cross involving ten cultivars found importance of both gca and sca and predominant role of additive gene effects.

In a 8 x 8 diallel analysis in urd bean genotypes, Malhotra (1983) observed that both additive and non additive gene effects were significant and important for seed yield with the preponderance of additive gene effects.

Yield and yield related characters were investigated in six cowpea genotypes and their fifteen possible non reciprocal crosses by Zaveri *et al.* (1983) and reported significance of both gca and sca variances with predominance of non addditive genetic variance.

Wilson *et al.* (1985) in an analysis of diallel cross using five varieties of greengram showed the existence of both additive and non additive gene action for seed yield per plant. The variance due to gca was reported to be much higher than that due to sca indicating the predominance of additive gene action in the expression.

Combining ability analysis in mungbean by Chowdhury (1986) using eight parents in a half diallel cross showed significant gca and sca variances for seed yield per plant. Additive and nonadditive gene actions were important for this character.

Combining ability analysis in a diallel cross of seven frenchbean cultivars conducted by Singh and Saini (1986) revealed significant gca and sca effects for yield per plant and reported the predominance of gca effect for this character indicating additive gene action.

A line x tester analysis involving four testers and ten lines of cowpea indicated that both gca and sca were important for seed yield (Mishra *et al.*, 1987)

Singh *et al.* (1987) in the combining ability analysis using a diallel cross of ten blackgram lines reported highly significant gca and sca, both in F_1 and F_2 generations, for grain yield. The estimates of variance due to sca was reported to be greater than variance due to gca indicating predominance of non additive gene action.

Eight chickpea lines and their twenty eight F_1 s' were studied for combining ability by Yadavendra and Sudhirkumar (1987) and found that non additive gene action was predominant for grain yield.

Haque *et al.* (1988) in a line x tester analysis with six urdbean lines of diverse origin and four testers reported that higher sca effect for yield was observed in the cross PLV 652 and T 9 and sca variance was higher indicating nonadditive gene action.

Five lines and five testers of chickpea and their F_2 and parents were studied to estimate their combining ability and reported that the sca variance were greater than gca for yield (Bahl and Kumar, 1989).

Saxena and Sharma (1989) estimated combining ability in mungbean and reported that both gca and sca variances were significant for yield per plant in F_1 and F_2. In general, mean square due to gca was of greater magnitude, suggesting the preponderance of additive gene action.

A 7 x 7 diallel cross in greengram by Natarajan *et al.* (1990) revealed the importance of both additive and non additive gene action and predominance of additive gene action.

Kaliya *et al.* (1991) estimated the combining ability for seed yield and its components over environments in black gram and reported significant mean sum of square due to sca for seed yield indicating dominance gene action.

Yield and yield related characters were investigated in eight mungbean genotypes and their 28 F_1 s by Saxena and Sharma (1992) in a diallel analysis and reported importance of additive as well as non additive variances and predominance of additive variances.

In a combining ability analysis of 4 line x 4 tester cross of cowpea by Thiyagarajan *et al.* (1993) variance due to gca and sca was predominant and non additive gene action prevalent for seed yield per plant.

Six chick pea cultivars and their 15 F_1 hybrids were studied by Katiyar and Katiyar (1993). No direct association could be established between the gca of the parents involved in the crosses and sca. The best combinations for yield per plant generally involved average gca x low sca parent crosses, indicating epistatic gene action.

In a line x tester analysis involving five lines and three testers, Kumar (1993) concluded the presence of both additive and non additive gene action for grain yield in cowpea. The mean square due to sca was reported to be high indicating the preponderance of non additive gene action for the character.

In a line x tester analysis involving four lines and five testers in mung bean Naidu and Satyanarayana (1993) found that nonadditive gene action was mainly responsible for seed yield per plant.

Twenty hybrids from, F_1 and F_2 of a 4 x 5 line x tester cross of *Vigna radiata* were evaluated by Rosaiah *et al.* (1994). Estimates of variance due to sca were higher than those due to gca for seed yield in both F_1 and F_2 indicating nonadditive gene action.

In chickpea, combining ability was estimated in a cross of 5 line x 3 tester by Mishra and Yadav (1994). They reported the importance of sca variance for seed yield and non additive gene action was responsible for the character.

2.13 Hundred seed weight

Combining ability analysis in a 5 x 5 diallel set in gram for seed yield and hundred seed weight revealed that additive gene action was predominant for hundred seed weight (Singh *et al.*, 1975).

In the half diallel cross of eight cowpea varieties along with parents carried out by Chauhan and Joshi (1981) revealed that both general and specific combining abilities were important for hundred seed weight. The gca variance was higher than sca indicating predominant role of additive gene action.

A diallel cross with six parents in urdbean revealed that both additive and nonadditive effects were important for hundred seed weight (Sandhu *et al.*, 1981).

Venkateswarlu and Singh (1981b) while analysing the combining ability in peas in a diallel cross involving ten cultivars found importance of both gca and sca and predominant role of additive gene action for hundred seed weight.

Combining ability studies in pea with 10 x 10 diallel crossing revealed the significance of gca and sca and higher magnitude of additive genetic variance than dominance variance for hundred seed weight (Dubey and Lal.,1983).

Malhotra (1983) in a 8 x 8 diallel analysis of black gram found the importance of both gca and sca variances for hundred seed weight. Both additive and nonadditive gene effects were significant and important for this character.

Wilson *et al.* (1985) in the analysis of the diallel cross among five varieties of greengram showed the existence of both additive and non additive gene action for hundred seed weight. Additive gene action was significant for this character.

The combining ability analysis using 39 hybrids, three lines and 13 testers in pigeonpea by Patel *et al.* (1987) revealed a significant role of additive and nonadditive gene action with predominance of additive gene action.

Yadavendra and Sudhirkumar (1987) studied eight chickpea lines and 28 F_1 s' for combining ability and reported that hundred seed weight is controlled by additive gene action.

In a study with six genotypes of chickpea and their hybrids Katiyar *et al.* (1988) reported significant gca and sca for hundred seed weight and suggested the importance of additive and nonadditive gene effects with a predominant role of nonadditive gene action for the trait.

Combining ability analysis in six parent diallel cross in cowpea conducted by Thiyagarajan *et al.* (1990) revealed that both additive and nonadditive gene effects were important for hundred seed weight. They also reported the preponderance of nonadditive gene effects for the character.

Combining ability analysis by Sood and Garten (1991) in a 9 x 9 diallel cross in blackgram revealed that the ratio of additive to dominance variance was less than unity for hundred seed weight indicting preponderance of dominance gene action for this character.

In a line x tester analysis in cowpea Kumar (1993) concluded the importance of additive gene action for the character hundred seed weight.

In an analysis of 4 lines x 5 testers in mungbean by Naidu and Satyanarayana (1993) sca variance was much higher for 100 seed weight indicating non additive gene action.

Thirty genotypes derived by diallel crossing of 5 Lentil varieties were studied by Singh and Singh (1993). They reported additive and non additive variances for this character.

In a line x tester analysis of 4 lines x 3 testers in cowpea, Thiyagarajan *et al.* (1993) found that sca variance was more than gca indicating predominance of non additive gene action for 100 seed weight.

Rosaiah *et al.* (1994) in a combining ability analysis involving 4 line x 5 testers of *Vigna radiata* found that the estimates of variance due to gca was higher than those due to sca for 100 seed weight indicating additive gene action.

Combining ability studies in cowpea carried out by Sawant (1995) showed that both gca and sca variances were highly significant for hundred seed weight. Additive gene effect was predominant for this trait.

A line x tester analysis by Sreekumar (1995) in cowpea observed significant gca and sca variances for hundred seed weight indicating the presence of additive and non additive genetic component. A predominant role of non additive gene action was also reported.

2.14 Seed protein content

In a 4 line x 5 tester cross in greengram by Naidu and Satyanarayana (1993) revealed that gca variance was higher for seed protein content and additive gene action was important for this character.

Significant sca variances than gca for seed protein was reported by Rosaiah *et al.* (1994) in a line x tester analysis of 4 lines x 5 testers in greengram indicating nonadditive gene action.

Sadhu *et al.* (1994) in a combining ability analysis of half diallel cross using ten *Vigna radiata* cultivars reported that mean square due to gca for seed protein were higher than those due to sca indicating the importance of additive gene action.

2.15 Harvest index

Pande *et al.* (1979) in a 9 x 9 diallel cross studied yield and yield components in bengalgram and reported highly significant gca and sca variances for harvest index. They also reported predominance of additive gene action for the character.

Combining ability analysis for physiological traits in pea using F_1 s' of 14 lines and three testers conducted by Katiyar *et al.* (1987) indicated the predominance of nonadditive gene action for harvest index.

Combining ability analysis in a diallel cross of ten black gram lines for yield and its components by Singh *et al.* (1987) showed greater estimate of sca variance than the respective gca variance for harvest index, indicating predominance of non additive gene action.

Hazarika *et al.* (1988) estimated combining ability in a line x tester analysis in pigeonpea and reported significance of both additive and nonadditive variances for yield.

Patel *et al.* (1988) in combining ability analysis in mungbean using 7 x 7 diallel excluding reciprocals, revealed significant gca and sca variances for harvest index, showing additive and non additive gene effects.

Combining ability analysis in cross involving five male and nine female tall and dwarf types in chick pea by Salimath and Bahl (1989) showed predominance of non additive gene action for harvest index.

Half diallel of seven short duration pigeonpea lines was evaluated in the F_1 and F_2 generation by Saxena *et al.* (1989) and reported the preponderance of additive gene action.

In soybean Gadag *et al.* (1990) noticed significant variation among parents and crosses for harvest index and reported that both gca and sca variances were highly significant. They also reported predominance of nonadditive gene action for harvest index.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present research programme was carried out at the department of plant breeding, College of Agriculture, Vellayani, Thiruvananthapuram during 1996-97.

3.1 MATERIALS

The experimental material consisted of eight black gram varieties as parents and their fifteen hybrids, the parents consisted of five lines and three testers. The lines were already identified as drought tolerant in a P.G. project in the K.A.U by Rani (1989). The testers were the recommended high yielding varieties. The lines, testers and their hybrids are detailed in the table 1.

3.2 METHODS

3.2.1 Experiment 1

A. **Selfing** : The three lines and five testers were first raised for seed multiplication in the field during May 1996 and allowed for self pollination . The plants were harvested, pods dried, seeds extracted, cleaned and kept in separate packets.

Table 1 **Details of parents and their hybrids**

No.	Treatments	Parents / Hybrids	
A)	LINES : 5		
	L_1	TAU 2	Drought tolerant
	L_2	PDU 5	Drought tolerant
	L_3	CoBG 302	Drought tolerant
	L_4	PDU 101	Drought tolerant
	L_5	T 9	Drought tolerant
B)	TESTERS : 3		
	T_1	Co BG 303	High yielding
	T_2	VB 11	High yielding
	T_3	WBG 67	High yielding
C)	HYBRIDS : 15		
	L_1T_1	TAU 2 x CoBG 303	
	L_1T_2	TAU 2 x VB 11	
	L_1T_3	TAU 2 x WBG 67	
	L_2T_1	PDU 5 x CoBG 303	
	L_2T_2	PDU 5 x VB11	
	L_2T_3	PDU 5 x WBG 67	
	L_3T_1	CoBG 302 x CoBG 303	
	L_3T_2	CoBG 302 x VB11	
	L_3T_3	CoBG 302 x WBG 67	
	L_4T_1	PDU101 x CoBG 303	
	L_4T_2	PDU 101 x VB11	
	L_4T_3	PDU 101 x WBG 67	
	L_5T_1	T 9 x CoBG 303	
	L_5T_2	T 9 x VB11	
	L_5T_3	T 9 x WBG 67	

B. Line x Tester Hybridization Programme

The parents for crossing were raised in pots and hybridization was done during October - November 1996. To obtain synchronized flowering, lines and testers were sown on staggered dates.

Yellowish green flower buds in the lines, which were likely to open next day morning were emasculated, incising through the keel petals in the evening (4 - 6 PM.). This was followed by pollination next morning (7 to 10 AM) using pollen grains from the respective male parent. The pollinated flower buds were suitably protected by keeping the plants in insect proof cages and were labelled. The pods in each cross were collected separately, seed extracted, cleaned, dried and kept for experiment II.

3.2.2 Experiment II

Five lines, three testers and their fifteen hybrids were grown adopting randomised block design with three replications in the uplands in the college of Agriculture, Vellayani during summer 1997.

Seeds were dibbled at a spacing of 25 x 15 cm. so that 75 plants were accommodated in each plot. The cultural and management practices were followed as per the Package of Practices Recommendations Crops' 93 of the Kerala Agricultural University (1993). However, irrigation was provided only on life saving basis. Data on various characters were recorded replication wise, from a random sample of five plants per treatment by completely excluding the border rows and the mean values were used for statistical analysis.

Observations were recorded on following characters and the mean values were used for statistical analysis.

i. **Drought related characters**

a) **Duration up to fifty percent flowering**

Recorded as the number of days taken from the date of sowing to approximately fifty percent flowering.

b) **Duration of the crop**

Recorded as the mean number of days taken from the date of sowing to the final harvest of the crop.

c) **Leaf Area Index (LAI) at fifty per cent flowering**

Leaf area index was measured from each plot when the crop was at fifty per cent flowering using a leaf area meter. All the leaves of plant were fed to the leaf area meter separately and the total leaf area was calculated. The leaf area index was calculated using the following formula suggested by William (1946).

$$\text{Leaf area index} = \frac{\text{Total leaf area of the plant}}{\text{Ground area occupied (spacing)}}$$

d) **Leaf hairiness**

For scoring the leaf hairiness comparative evaluation was done and hairiness classified to less hairy, medium hairy and densely hairy.

e) **Leaf thickness** (mm)

Leaf thickness measured in mm using a screw gauge.

f) Number of stomata

For estimating number of stomata, fully opened and matured leaves were selected from the sample plants and leaf impressions were taken by applying a thin coat of nail polish on the lower leaf surface which was subsequently peeled off after drying. From these impressions ten microscopic fields (40 X 10x) were scored for number of stomata and the mean per microscopic field was estimated.

g) Root Shoot ratio

The ratio of the root dry weight to shoot dry weight was expressed as root / shoot ratio. From each sample plant root and shoot portions were separated, sun dried for two days, oven dried at 60 to 70 degree Celsius for one day, dry weights recorded, and the ratio was computed as dry wt. of root / dry wt. of shoot (including pod weight).

h) Spread of root at harvest

Root spread was measured at harvest placing the root system on a graph paper and measuring the spread at its broadest part. The root spread was expressed in cm.

i) Free proline content of leaves (%)

Fully expanded second leaf from top was collected from sample plant at fifty per cent flowering and the proline content was estimated by the method suggested by Bates *et al.* (1973).

Three random leaf samples collected from each plot were oven dried and well powdered. From the powdered sample 0.25 g was weighed out. and homogenized in 10 ml of 3% aqueous sulfo salicylic acid and the homogenate filtered through No. 2 Whattman filter paper. Two ml of the filtrate was reacted with two ml acid ninhydrin and two ml of glacial acetic acid in a test tube for one hour at 100^0 C and the reaction terminated in an icebath. The reaction mixture was extracted with four ml toluene, stirred vigorously with a test tube stirrer for 15 - 20 seconds and the absorbance read at 520 nm using toluene as blank. The proline content was determined from a standard curve and calculated on dry weight basis as follows.

$$\frac{(\mu g \text{ of proline / ml x ml of toluene}) \ [\text{ml of salicylic acid (10 ml)}]}{\text{ml of plant extract used (2 ml) x weight of sample}}$$

ii. **Yield related characters**

j) **Height of the plant** (cm)

The plant height was measured in cm. from ground level to the tip of the terminal bud.

k) **Number of branches per plant**

Total number of primary branches was recorded as their number of branches arising from each observational plant.

l) **Number of pods per plant**

Recorded as the total number of pods harvested in each plant.

m) **Number of seeds per pod**

The number of seeds from each pod in the observational plants were counted and the mean worked out.

n) **Grain yield per plant** (g)

This was recorded as weight in grams of harvested grains (economic yield) from the observational plants and mean worked out..

o) **Weight of hundred seeds** (g)

Random sample of hundred seeds was taken from each plot at harvest and mean weight recorded in grams.

p) **Seed protein content** (%)

The seeds were oven dried at 80 ^{0} C for 12 hours and finely ground in Wiley mill. The total nitrogen was calculated employing modified Micro Kjeldahl method.

Protein content of the grain was calculated by multiplying the percentage of nitrogen by the factor 6.25 (Simpson *et al.*, 1965).

q) **Harvest Index**

Harvest index was calculated by using the formula.

$$\text{Harvest index} = \frac{\text{Economic yield per plant}}{\text{Biological yield per plant.}}$$

$$\text{ie.,} \quad \frac{\text{grain yield per plant}}{\text{dry weight of plant excluding grains}}$$

Statistical Analysis

Analysis of variance (ANOVA) was done for all the characters and significance of differences among the types including parents and crosses was tested (Singh and Choudhary, 1979).

Combining ability analysis.

Combining ability analysis of the line x tester was done through Anova technique out lined by Dabholkar (1992). Anova is presented in table 2.

Table - 2 **ANOVA FOR LINE x TESTER**

Source	df	Mean Square	Expected Mean Square
Replication	r-1		
Treatments	n-1		
I. Parents	l+ t-1		
II. Parents x Crosses	1		
III. Crosses	lt - 1		
(a) Lines	l - 1	ML	$\sigma^2 + r\sigma^2$ sca + rt σ^2 gca(l)
(b) Testers	t - 1	MT	σ^2 e + $r\sigma^2$ sca + $rl\sigma^2$ gca (t)
(c) Line x Testers	(l-1)(t-1)	MLT	σ^2 e + $r\sigma^2$ sca
Error	(n-1)(r-1)	ME	σ^2 e
Total	nr-1		

Where n = number of treatment materials = l + t + lt

r = number of replication

l = number of lines

t = number of testers

To estimate the additive and dominance genetic components of variance (σ^2 a and σ^2 d), the following relationships are used.

$$\sigma^2 \text{ gca (Lines)} = \frac{(ML - MLT)}{rt} = \text{CoV. H. S. (lines)}$$

$$\sigma^2 \text{gca (Testers)} = \frac{(MT - MLT)}{rl} = \text{CoV. H.S (testers)}$$

$$\sigma^2 \text{ sca (Crosses)} = \frac{(MLT - ME)}{r}$$

σ^2 gca = 1/4 σ^2 a if inbreeding coefficient is zero
σ^2 sca = 1/4 σ^2 d
so σ^2 a = 4 σ^2 sca
σ^2 d = 4 σ^2 sca

The significance of σ^2 a is tested from the

F [(l - 1), (l - 1) (t- 1)] = ML / MLT for lines and

F [(t - 1), (l - t) (t - 1)] = MT / MLT for testers.

and that of σ^2 d from

F [(l - 1) (t - 1) , (n - 1) (r - 1)] = MLT / ME

A significant 'F' in the above cases is an indication of significant genetic difference among plants chosen as parents and the inconsistent behaviour of the female over male parent or vice versa and thus providing an information on the relative ability of number of male and female parents to produce desirable hybrids.

Estimation of gca and sca effects

The model used to estimate the gca and sca effects of ijkth observation was as follows.

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

I = 1, 2, 3, ..., l

$j = 1, 2, 3, \ldots\ldots, t$

$k = 1, 2, 3, \ldots\ldots, r$

where μ = population mean

g_i = gca effect of i^{th} line

g_j = gca effect of j^{th} tester

s_{ij} = sca effect of ij^{th} combination

e_{ijk} = random error component associated with ijk^{th} observation.

The individual effects were estimated as follows.

1. mean $= \dfrac{X_{...}}{ltr}$

2. gca effect of lines $g_i = \dfrac{X_{i..}}{tr} \qquad \dfrac{X_{...}}{ltr}$

3. gca effect of testers $g_j = \dfrac{X_{.j.}}{lr} - \dfrac{X_{...}}{ltr}$

4. sca effect in combinations

$$S_{ij} = \frac{X_{ij.}}{r} - \frac{X_{i..}}{tr} - \frac{X_{.j.}}{lr} + \frac{X_{...}}{ltr}$$

where $X_{...}$ = total of all hybrid combinations

$X_{i..}$ = total of i^{th} line over t testers and r replications

$X_{.j.}$ = total of j^{th} tester over i lines and r replications

$X_{ij.}$ = total of the hybrids i^{th} line and j^{th} tester over r replications

The standard error pertaining to gca effect of lines and testers and sca effects in different combination were calculated as given below.

Lines : SE (g_i) = $(Ml/ rt)^{1/2}$

Testers ; SE (g_j) = $(M_t/rl)^{1/2}$

Crosses : SE (s_{ij}) = $(M_e /r)^{1/2}$

Proportional contribution of lines, testers and line x tester to total variance is given as

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

$$\text{Contribution of testers} = \frac{SS(T) \times 100}{SS\ (Crosses)}$$

$$\text{Contribution of line x tester} = \frac{SS\ (L \times T) \times 100}{SS\ (Crosses)}$$

Where SS(L) = Sum of squares due to lines
SS(T) = Sum of squares due to testers
SS(L x T) = Sum of squares due to line x tester

RESULTS

RESULTS

Analysis of variance of sixteen characters presented in the Table 4a and 4b revealed that all the characters exhibited significant genotypic differences. The results on mean performance and combining ability analysis are presented below

Mean performance

The treatment effects were significant with respect to all the characters. Mean performance of lines, testers and hybrids for different characters is presented in Table 3.a and 3.b

Shortest duration upto 50 per cent flowering among lines was observed in PDU 5 (39.32 days) and longest in CoBG 302 (43.38 days). Among testers, minimum days taken for 50 per cent flowering was by VB 11 (39.29) and maximum by WBG 67 (42.31). However, the lines or testers did not differ significantly for this character. Among crosses PDU 101 x WBG 67 recorded minimum days upto 50 per cent flowering (37.27) and was followed by TAU 2 x CoBG 303 (42.08). The cross PDU 101 x VB 11 took the maximum duration upto 50 per cent flowering (56.44 days) followed by PDU 101 x CoBG 303 (52.33 days).

Shortest duration of the crop was shown by T 9 (67.61 days) and longest duration by CoBG 302 (77.3 days) among lines. Among testers, the values were 68.69 in WBG 67 and 74.92 days in VB 11 respectively. Among crosses, the cross T 9 x WBG 67 recorded shortest duration (65.11 days) and PDU 5 x WBG 67 longest (80.13 days). The varieties in lines and in hybrids differed significantly for this character.

Table 3 (a) **Mean performance of lines, testers and hybrids for drought related characters**

	Days to 50% flowering	Duration of the crop (days)	LAI	Leaf thickness (mm)	Stomata / microscopic field	Root shoot ratio	Root spread (cm)	Proline content µg/g
Lines								
L_1 TAU 2	40.32	68.63	4.53	0.199	45.40	0.128	31.18	976.8
L_2 PDU 5	39.32	69.74	6.10	0.143	38.00	0.104	27.67	799.2
L_3 CoBG 302	43.38	77.30	4.32	0.191	46.40	0.093	22.00	651.2
L_4 PDU 101	40.52	73.63	3.40	0.151	48.07	0.094	21.67	1065.6
L_5 T 9	39.48	67.61	3.93	0.191	46.40	0.141	22.87	1509.6
Testers								
T_1 Co BG 303	40.59	71.13	1.93	0.167	44.67	0.121	19.20	976.8
T_2 VB 11	39.29	74.92	2.24	0.183	38.47	0.103	21.52	1085.2
T_3 WBG 67	42.31	68.69	2.37	0.175	32.47	0.114	29.92	1332.0
Hybrids								
L_1T_1	42.08	74.63	3.26	0.151	41.47	0.128	19.00	710.4
L_1T_2	50.37	75.27	5.32	0.171	31.13	0.074	23.98	1243.2
L_1T_3	48.62	78.26	5.13	0.207	38.47	0.143	29.60	976.8
L_2T_1	48.33	80.03	2.83	0.159	38.47	0.112	24.17	710.4
L_2T_2	46.33	79.89	2.71	0.191	42.07	0.146	18.12	976.8
L_2T_3	51.15	80.13	8.71	0.183	42.40	0.163	20.77	1332.0
L_3T_1	42.33	78.67	6.91	0.191	41.53	0.132	34.90	888.0
L_3T_2	49.27	78.59	3.67	0.191	38.40	0.122	30.47	828.8
L_3T_3	51.33	78.15	4.96	0.191	32.87	0.073	30.37	532.8
L_4T_1	52.33	72.26	3.37	0.199	45.80	0.094	15.00	444.0
L_4T_2	56.44	74.92	3.50	0.199	34.20	0.109	12.43	1361.6
L_4T_3	37.27	68.11	5.66	0.143	38.07	0.150	31.50	1065.6
L_5T_1	45.33	68.19	2.10	0.199	42.20	0.095	21.97	1036.0
L_5T_2	43.15	66.15	2.62	0.255	45.73	0.150	33.27	1065.6
L_5T_3	45.35	65.11	3.87	0.206	32.00	0.134	22.03	1036.0
CD (1 % level)	0.59	1.65	0.04	0.04	3.16	0.02	4.65	184.76
CD (5 % level)	0.44	1.23	0.03	0.03	2.37	0.01	3.48	138.23

Table 3(b) Mean performance of lines, testers and hybrids for yield related characters

	Height of the plant (cm)	No. of branches per plant	No. of pods per plant	No. of seeds per pod	Grain yield per plant (g)	100 seed weight (g)	Seed protein (%)	Harvest index
Lines								
L_1 TAU 2	41.00	3.07	26.85	5.60	10.40	4.72	23.73	0.40
L_2 PDU 5	56.93	3.07	31.07	6.20	6.38	4.62	26.82	0.37
L_3 CoBG 302	47.60	2.87	33.07	5.93	15.42	4.38	23.77	0.77
L_4 PDU 101	54.80	3.00	31.13	6.40	9.34	4.60	18.97	0.41
L_5 T 9	45.60	2.53	32.33	6.07	13.53	4.57	19.41	0.70
Testers								
T_1 Co BG 303	52.55	2.33	39.02	5.38	21.80	4.77	20.15	0.84
T_2 VB 11	41.86	3.40	26.13	6.07	15.01	4.30	23.57	0.75
T_3 WBG 67	55.27	2.40	25.87	6.87	11.46	5.38	20.63	0.58
Hybrids								
L_1T_1	41.13	3.13	28.20	5.80	8.22	4.78	19.76	0.54
L_1T_2	43.60	2.80	28.47	5.87	9.04	4.83	24.93	0.54
L_1T_3	47.87	3.00	24.67	5.93	4.75	4.22	18.84	0.26
L_2T_1	54.33	2.33	27.33	5.93	6.95	4.40	25.52	0.54
L_2T_2	56.93	2.20	27.40	6.87	7.93	4.79	26.06	0.47
L_2T_3	51.60	2.27	24.47	6.80	8.06	5.24	19.04	0.42
L_3T_1	47.33	2.27	35.53	5.93	10.81	4.83	21.82	0.56
L_3T_2	47.73	3.00	29.07	6.27	7.46	4.41	20.83	0.43
L_3T_3	42.33	2.87	34.47	6.53	7.35	4.29	17.74	0.36
L_4T_1	44.13	2.93	20.80	6.90	3.58	5.24	19.17	0.21
L_4T_2	46.90	1.70	25.87	6.00	8.67	3.91	23.70	0.53
L_4T_3	57.73	3.40	50.07	6.73	11.82	5.69	26.96	0.58
L_5T_1	42.93	2.93	39.27	6.60	16.29	4.15	20.95	0.75
L_5T_2	52.73	3.47	56.67	5.40	12.44	4.16	22.05	0.67
L_5T_3	45.53	3.13	54.93	6.40	19.05	4.81	20.83	0.82
CD (1 % level)	8.32	1.16	12.03	0.64	0.68	0.19	0.67	0.03
CD (5 % level)	6.22	0.87	9.00	0.48	0.51	0.14	0.50	0.02

Highest value for leaf area index was shown by PDU 5 (6.10) and lowest by PDU 101 (3.40) among lines. Among testers, this was highest in WBG 67 (2.37) and lowest in CoBG 303 (1.93). Highest value for leaf area index (8.71) was recorded in the hybrid PDU 5 x WBG 67 and lowest by T 9 x CoBG 303 (2.10). The hybrids and parent vs crosses differed significantly in this character.

Regarding leaf thickness the values ranged from 0.143 mm in PDU 5 to 0.199 mm in TAU 2 among lines. Among testers the range was from 0.167 mm in CoBG 303 to 0.183 mm in VB 11. The crosses differed significantly for this character and the range was from 0.143 mm in PDU 101 x WBG 67 to 0.255 mm in T 9 x VB 11 among hybrids.

Stomatal distribution on lower surface of leaves ranged from 38 counts per microscopic field (cpf) in PDU 5 to 48.07 cpf in PDU 101 among lines. Among testers the range was from 32.47 cpf in WBG 67 to 44.47 cpf in CoBG 303. Here also the crosses differed significantly among them the count ranged from 31.13 cpf in TAU 2 x VB 11 to 45.8 cpf in PDU 101 x CoBG 303.

Highest and lowest root shoot ratios were recorded by T 9 (0.141) and CoBG 302 (0.093) respectively among lines. The range in the value was from 0.121 in CoBG 303 to 0.103 in VB 11 among testers. The value ranged from 0. 163 in PDU 5 x WBG 67 to 0.073 in CoBG 302 x WBG 67 among hybrids. For root shoot ratio, hybrids showed significant difference while lines and testers did not.

The line, TAU 2 exhibited maximum average spread of roots at harvest

(31.18 cm) and PDU 101 minimum (21.67 cm). Among testers, WBG 67 and CoBG 303 recorded maximum (29.92 cm) and minimum (19.20 cm) values respectively for the character. The cross CoBG 302 x CoBG 303 had maximum root spread (34.90 cm) and PDU 101 x VB 11 minimum (12.43 cm). The hybrids differed significantly for the character while the lines and testers did not.

Proline content in leaves ranged from 651.2 µg /g in CoBG 302 to 1509.6 µg / g in T 9 among lines. In testers, the range was between 976.8 µg / g in CoBG 303 to 1332.0 µg / g in WBG 67. On the other hand the cross PDU 101 x VB 11 had maximum proline content (1361.6 µg / g) while PDU 101 x CoBG 303 had minimum (444.0 µg /g). The hybrids and parents vs crosses differed significantly in this character.

Among lines PDU 5 was the tallest (56.93 cm) and TAU 2 the shortest (41 cm). WBG 67 was the tallest (55.27 cm) among testers and VB 11 the shortest (41.86 cm). The cross PDU 101 x WBG 67 recorded maximum height (57.73 cm) and TAU 2 x CoBG 303 minimum (41.13 cm). The crosses differed significantly for this character.

In lines, number of branches per plant ranged from 3.07 in TAU 2 and PDU 5, to 2.53 in T 9. Among testers the range was from 3.4 in VB 11 to 2.33 in CoBG 303. In hybrids the range was from 3.47 in T 9 x VB 11 to1.7in PDU 101 x VB 11. There was no significant variation among lines or testers.

Maximum number of pods per plant was produced by the line CoBG 302 (33.07) and minimum by TAU 2 (26.85). The tester CoBG 303 produced maximum pods per plant (39.02) and WBG 67 minimum (25.87). The cross

T 9 x VB 11 produced the highest number of pods per plant (56.67) while PDU 101 x CoBG 303 showed the lowest (20.80). The treatments in lines and hybrids showed significant difference for this character, while the testers did not.

The range showed in number of seeds per pod among lines was from 5.6 in TAU 2 to 6.4 in PDU 101 and in testers the value ranged from 5.38 in CoBG 303 to 6.87 in WBG 67. In hybrids it ranged from 5.4 in T 9 x VB 11 to 6.9 in PDU 101 x CoBG 303. The hybrids differed significantly for number of seeds per pod.

The highest grain yield per plant was recorded by CoBG 302 (15.42 g) and the lowest by PDU 5 (6.38 g) among lines.The values ranged from 21.80 g in CoBG 303 to 11.46 g in WBG 67 among testers. Among hybrids, T 9 x WBG 67 had maximum grain yield per plant (19.05 g) and PDU 101 x CoBG 303, the minimum (3.58 g). The treatments in lines and in hybrids differed significantly.

Mean weight of 100 seeds ranged from 4.38 g in CoBG 302 to 4.72 g in TAU 2 among lines, and from 4.30 g in VB 11 to 5.38 g in WBG 67 among testers. Maximum 100 seed weight (5.69 g) was recorded in the cross PDU 101 x WBG 67 and minimum (3.91 g) in the cross PDU 101 x VB 11. The crosses were significantly different in the character.

Seed protein content (percentage) had a range of 26.82 in PDU 5 to 18.97 in PDU 101 among lines, and 23.57 in VB 11 to 20.15 in CoBG 303 among testers. The seeds in the cross, PDU 101 x WBG 67 contained

Table 4 (a) ANOVA of drought related characters

Source	df	Mean squares							
		Days to 50% flowering	Duration of the crop	LAI	Leaf thickness	Stomata / microscopic field	Root shoot ratio	Spread of root	Proline content
Replication	2	0.117	0.297	0.0004	0.0001	3.43	0.00003	2.285	11080.0
Treatment	22	79.244**	72.517**	8.5000**	0.0089**	74.99**	0.00185**	109.050**	216719.1**
parents	7	6.556**	36.173**	5.9670**	0.0012**	90.37**	0.00087**	59.125**	225298.6**
Crosses	14	71.654**	85.114**	9.8170**	0.0022**	60.20**	0.00237**	141.801**	215910.3**
Parents Vs crosses	1	694.313**	150.570**	7.8050**	0.0031**	174.43**	0.00141**	0.004	167986.0**
Lines	4	24.836	270.750**	7.0360	0.0030	19.36	0.00132	206.923	119594.0
Testers	2	38.020	4.258	20.7700	0.0019	100.74	0.00160	63.176	446312.0
L x T	8	103.472**	12.510**	8.4680**	0.0018**	70.49**	0.00309**	128.896**	206468.0**
Error	44	0.071	0.557	0.0003	0.0003	2.06	0.00007	4.447	7023.8

* Significant at 5 % level.
** Significant at 1 % level.

Table 4 (b) ANOVA of yield related characters

Source	df	Mean squares							
		Height of the plant	No. of branches per plant	No. of pods per plant	No. of seeds per pod	Grain yield per plant	100 seed weight	Seed protein content	Harvest index
Replication	2	5.49	0.222	99.46*	0.023	0.003	0.0096	0.521	0.0011
Treatment	22	92.74**	0.577*	277.20**	0.638**	61.102**	0.5620**	23.403**	0.0926**
parents	7	117.95**	0.423	58.63	0.631**	65.966**	0.3220**	22.654**	0.1090**
Crosses	14	84.98**	0.693*	395.61**	0.642**	49.925**	0.7220**	25.379**	0.0819**
Parents Vs crosses	1	24.97	0.031	149.45*	0.625**	183.535**	0.0053	0.978**	0.1290**
Lines	4	139.61	1.069	848.52**	0.735	118.126**	0.4730	19.407	0.1570
Testers	2	56.43	0.339	204.75	0.611	5.711	0.6950	32.191	0.0071
L x T	8	64.80**	0.594	216.88**	0.604**	26.879**	0.8530**	26.662**	0.0630**
Error	44	14.23	0.278	29.79	0.084	0.096	0.0071	0.091	0.0002

* Significant at 5 % level.

** Significant at 1 % level.

Table. 5a General and specific combining abilities for drought related characters

	Days to 50% flowering	Duration of the crop (days)	LAI	Leaf thickness (mm)	Stomata / microscopic field	Root shoot ratio	Root spread (cm)	Proline content µg/g
Lines (gca)								
L_1 TAU 2	-0.289**	1.494**	0.262**	-0.0128*	-1.431**	-0.0064	-0.317	29.59
L_2 PDU 5	1.292**	5.460**	0.443**	-0.0113	1.858**	0.0186*	-3.493**	59.19
L_3 CoBG 302	0.332**	3.912**	0.870**	0.0020	-1.520**	-0.0127	7.399**	-197.33**
L_4 PDU 101	1.367**	-2.792**	-0.130**	-0.0089	0.236	-0.0040	-4.834**	9.87
L_5 T 9	-2.703**	-8.074**	-1.445**	0.0309**	0.858	0.0047	1.244	98.66**
SE	0.089	0.249	0.005	0.0060	0.478	0.0082	0.703	27.94
CD	0.253	0.709	0.015	0.0170	1.363	0.0029	2.004	79.65
Testers (gca)								
T_1 Co BG 303	-1.229**	0.199	-0.613**	-0.0093*	2.773**	-0.0100	-1.485	-189.44**
T_2 VB 11	1.799**	0.408*	-0.744**	0.0123**	-0.413	-0.0014	-0.857	147.99**
T_3 WBG 67	-0.570**	-0.606**	1.357**	-0.0030	-2.360**	0.0110	2.342**	41.44
SE	0.069	0.193	0.004	0.0046	0.370	0.0063	0.544	21.64
CD	0.196	0.549	0.012	0.0130	1.056	0.0022	1.552	61.70
Hybrids (sca)								
L_1T_1	-3.711**	-1.624**	-0.696**	-0.0159	1.004	0.0226	-3.710**	-76.96
L_2T_1	0.958**	-0.183	-1.305**	-0.0094	5.284**	-0.0188	4.633**	-106.56*
L_3T_1	-4.082**	0.001	2.347**	0.0093	1.160	0.0326*	4.474**	327.57**
L_4T_1	4.883**	0.296	-0.192**	0.0279**	3.671**	-0.0144	-3.093**	-323.63**
L_5T_1	1.953**	1.511**	-0.153**	-0.0119	-0.551	-0.0219	-2.304	179.57**
L_1T_2	1.548**	-1.190**	1.497**	-0.0175	-4.142**	-0.0396**	0.646	118.40*
L_2T_2	-4.070**	-0.532	-1.298**	0.0010	1.502	0.0071	-2.039	-177.59**
L_3T_2	-0.176	-0.284	-0.767**	-0.0123	1.213	0.0144	-0.588	-69.06
L_4T_2	5.959**	2.750**	0.064**	0.0063	-4.742**	-0.0072	-6.390**	256.53**
L_5T_2	-3.261**	-0.744	0.504**	0.0225*	6.169**	0.0253	8.368**	-128.26**
L_1T_3	2.163**	2.814**	0.801**	0.0334**	3.138**	0.0170	3.064**	-41.43
L_2T_3	3.112**	0.715	2.603**	0.0083	3.782**	0.0117	-2.594*	284.16**
L_3T_3	4.259**	0.283	-1.580**	0.0030	-2.373*	-0.0470**	-3.886**	-258.50**
L_4T_3	-10.842**	-3.046**	0.129**	-0.0341**	1.071	0.0217	9.480**	67.09
L_5T_3	1.308**	-0.767	-0.352**	-0.0106	-5.618**	-0.0034	-6.064**	-51.31
SE	0.153	0.431	0.009	0.0103	0.828	0.0141	1.217	48.39
CD	0.438	1.23	0.026	0.0290	2.361	0.0049	3.471	137.95

* Significant at 5 % level ** Significant at 1 % level

maximum protein (26.96 per cent) while those in CoBG 302 x WBG 67 contained the least protein content (17.74 per cent).

Harvest index was maximum (0.77) in CoBG 302 and minimum (0.37) in PDU 5 among lines. It was maximum (0.84) in CoBG 303 and minimum (0.58) in WBG 67 among testers. The cross T 9 x WBG 67 registered maximum value for harvest index (0.82) and PDU 101 x CoBG 303 minimum value (0.21).

Combining ability analysis

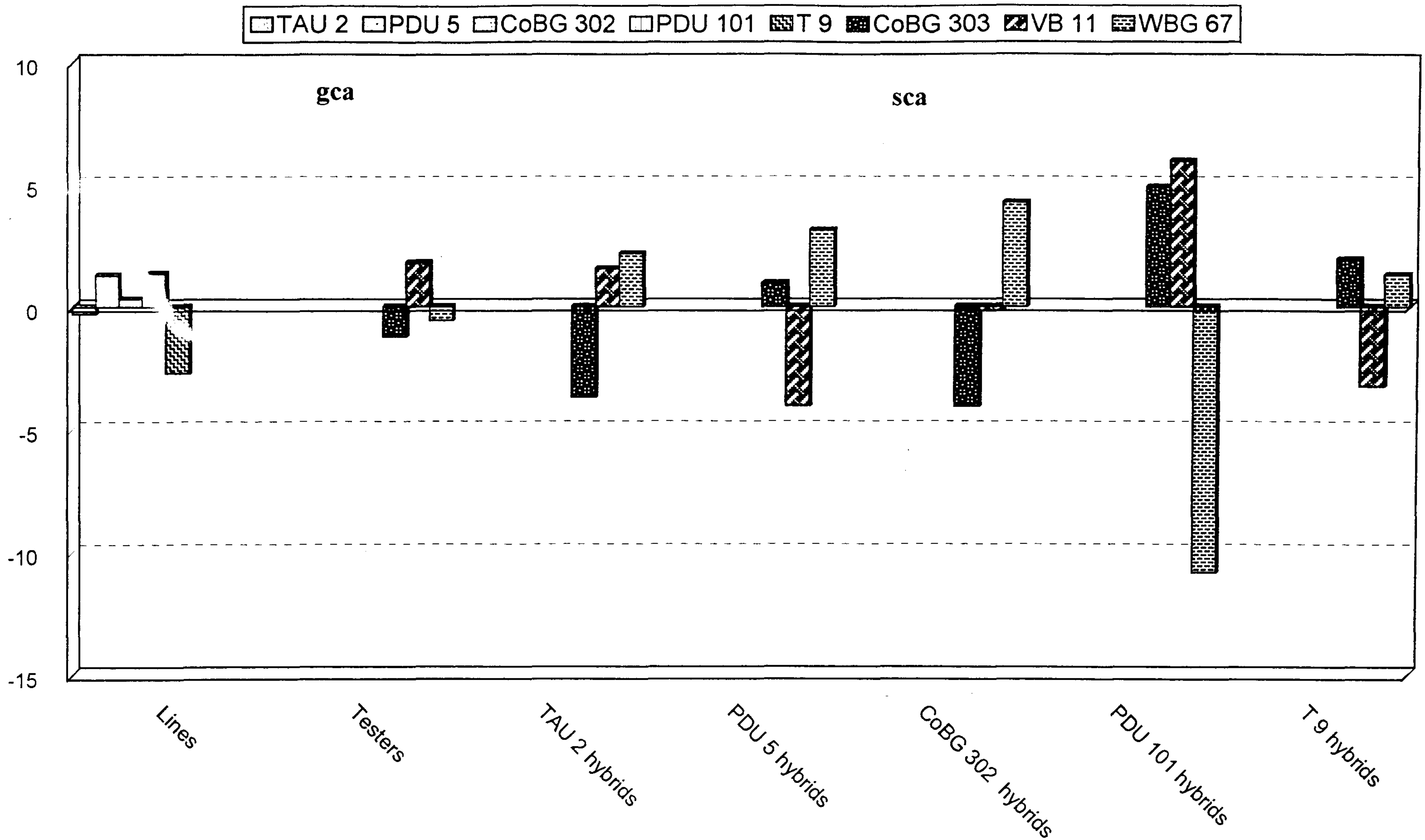
Analysis of variance of sixteen characters presented in the Table 4a and 4b revealed that all the characters exhibited significant genotypic differences. Hence all the characters were subjected to line x tester analysis to study the gene action in terms of general and specific combining abilities (gca and sca) are presented in Table 5.a and 5.b.

Days to fifty percent flowering

In the combining ability analysis for fifty per cent flowering, significant differences were observed among lines and testers for their general combining ability (gca). Among lines T 9 had significant negative gca (-2.703) while PDU 101 (1.367) had significant positive gca on par with PDU 5 (1.292). Among testers CoBG 303 had significant negative gca of -1.229 while VB 11 had a significant positive gca of 1.799 (Table 5.a and Fig. 1).

Among the crosses the cross PDU 101 x WBG 67 had maximum negative specific combining ability (sca) (-10.842) which was significantly different while the crosses CoBG 302 x CoBG 303 (-4.082), PDU 5 x VB 11 (-4.070) and TAU 2 x CoBG 303 (-3.711) had negative sca effects and were

Fig. 1 General and specific combining ability for days to 50 % flowering



on par. Crosses T9 x VB 11 (-3.261) and CoBG 302 x VB 11 (-0.176) also had negative sca effects. Maximum positive sca effect (5.959) was shown by the cross PDU 101 x VB 11 which was significantly different from all other crosses. All the crosses except the cross CoBG 302 x VB 11 had significant sca effect (Table 4a).

The ratio of variance due to gca to that due to sca equals 0.033 when inbreeding coefficient (F) was zero (Table 7).

Duration of the crop

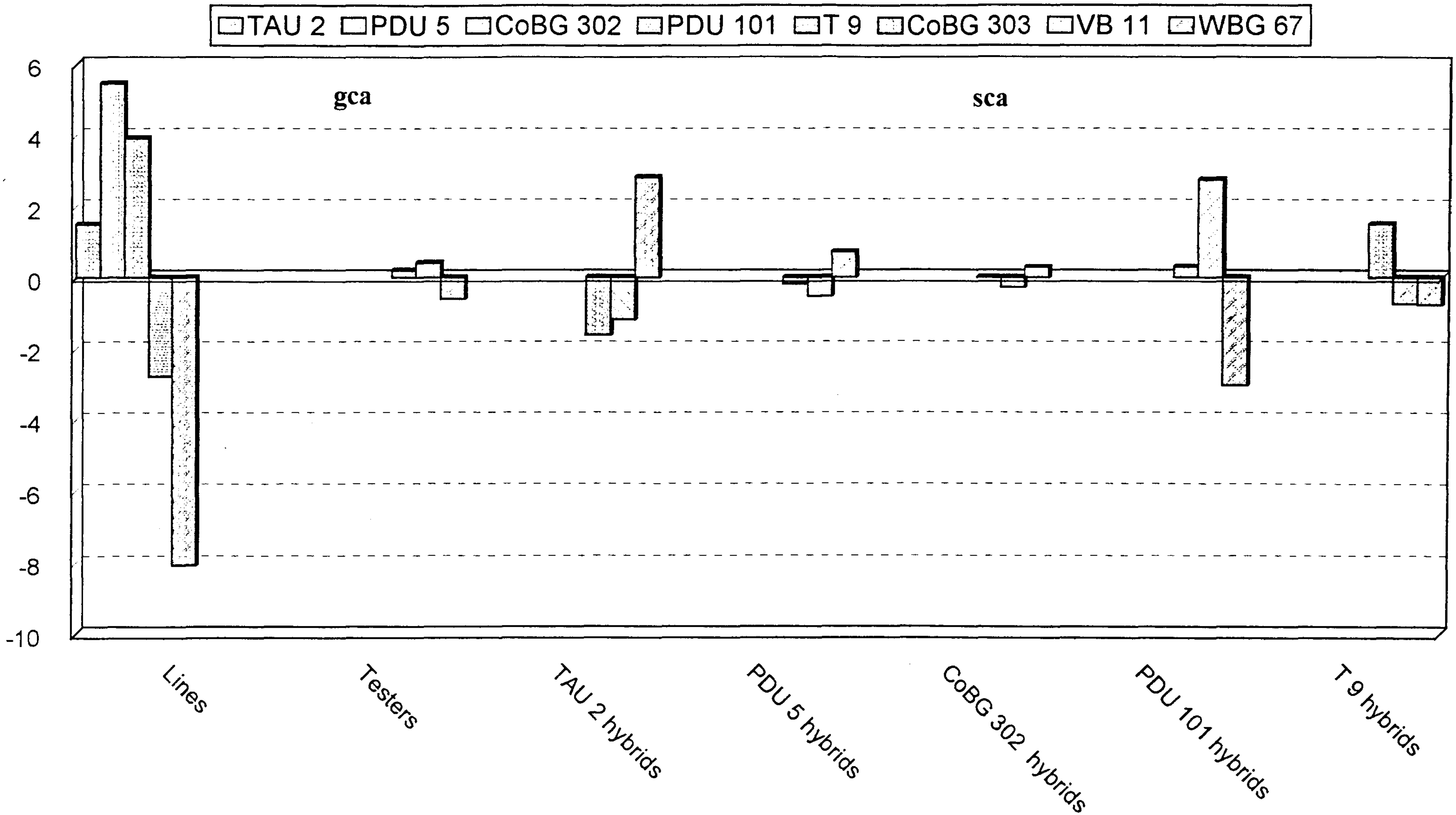
The combining ability analysis for duration of the crop showed that the lines and testers had significant gca effects (Table 5a and Fig. 2). Maximum positive gca was shown by PDU 5 (5.460) and maximum negative gca was shown by T 9 (-8.074). Among three testers significant negative gca was shown by WBG 67 (-0.606). VB 11 (0.408) and CoBG 303 (0.199) showed positive gca values.

Among hybrids, significant positive sca were shown by the crosses TAU 2 x WBG 67 (2.814), PDU 101 x VB 11 (2.750) and T 9 x CoBG 303 (1.511). The crosses of tester VB 11 had negative sca effects except in its cross with PDU 101 (2.750). The maximum negative sca was shown by the cross PDU 101 x WBG 67 (-3.046) followed by crosses TAU 2 x CoBG 303 (-1.624) and TAU 2 x VB 11 (-1.190). Nine crosses exhibited positive sca effects and six crosses negative. The ratio of variance due to gca to sca was 0.664 when the value of F was zero (Table 7).

Leaf area index

Table 5a and Fig. 3. depicts the combining ability effects for leaf area

Fig. 2 General and specific combining ability for duration of the crop



index (LAI) of the plant. All the lines had significant gca for LAI. CoBG 302 (0.870) had the highest value which was significantly different from all others. PDU 5 (0.443) and TAU 2 (0.262) also had significant positive gca effects. The highest negative value for LAI was shown by T 9 (-1.445) and was followed by PDU 101 (-0.130).

Testers also differed significantly, the highest positive gca for LAI was shown by WBG 67 (1.360) and other two had negative gca effects of which VB 11 (-0.744) was the highest.

All the hybrids showed significant sca effects. The positive value for sca was highest for the cross PDU 5 x WBG 67 (2.603) and was significantly different from all other crosses. Eight out of fifteen hybrids showed negative sca effect. The highest sca effect was shown by the cross CoBG 302 x WBG 67 (-1.580) which was significantly different from all crosses with negative effects and was followed by PDU 5 x CoBG 303 (-1.305) and PDU 5 x VB 11 (-1.298). The ratio of variance due to gca to that due to sca was less than one ie. 0.017 when inbreeding coefficient was zero (Table 7).

Leaf thickness

Table 5a and Fig. 4 provides an estimate of the general and specific combining ability effects for leaf thickness. It shows that significant and positive gca for lines was shown only by T9 (0.031 mm), while three other lines showed negative effects.

All the testers were on par with respect to gca effects for this character. Only VB 11 had positive value (0.012) while the other two testers were negative.

Fig. 3 General and specific combining ability for Leaf Area Index

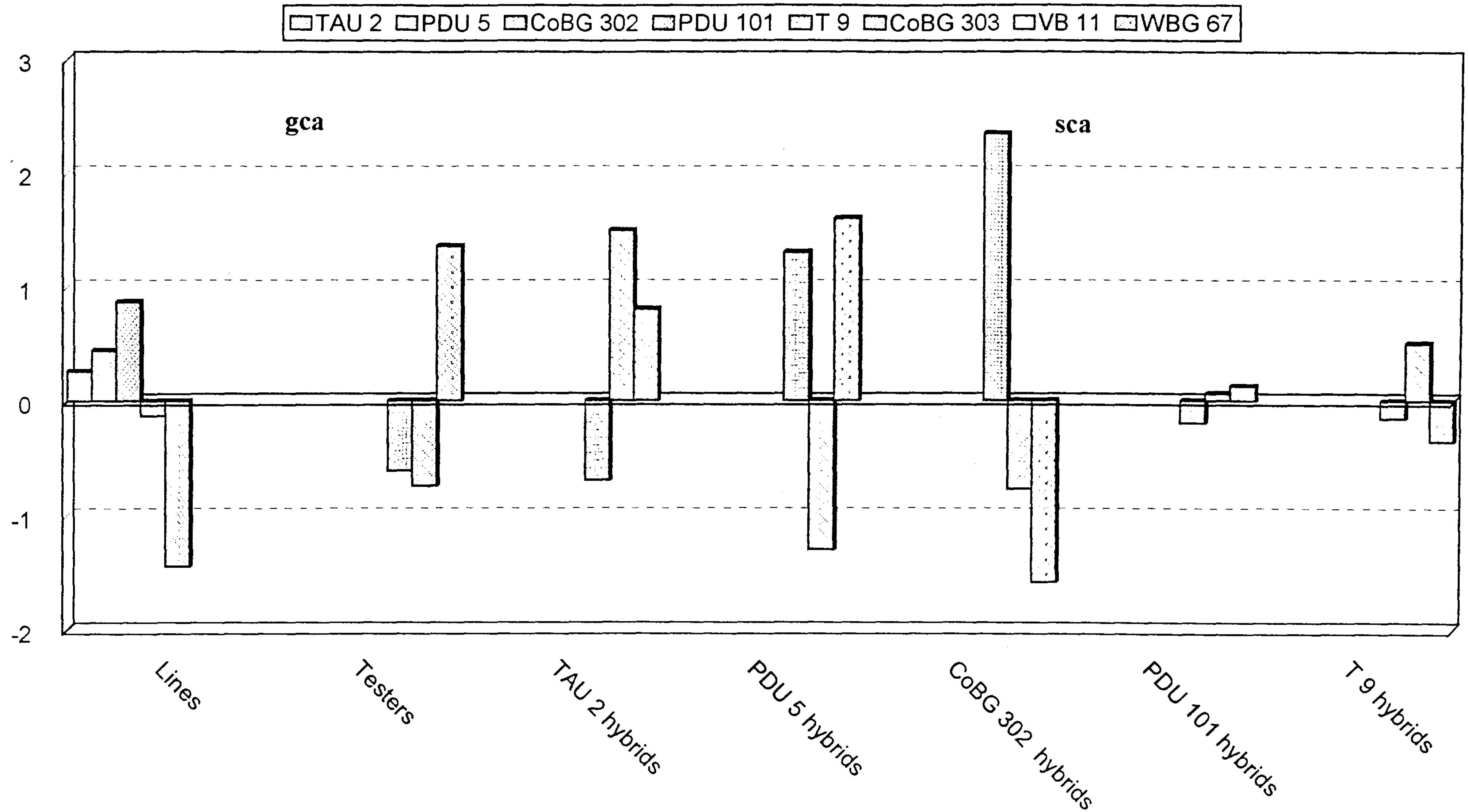
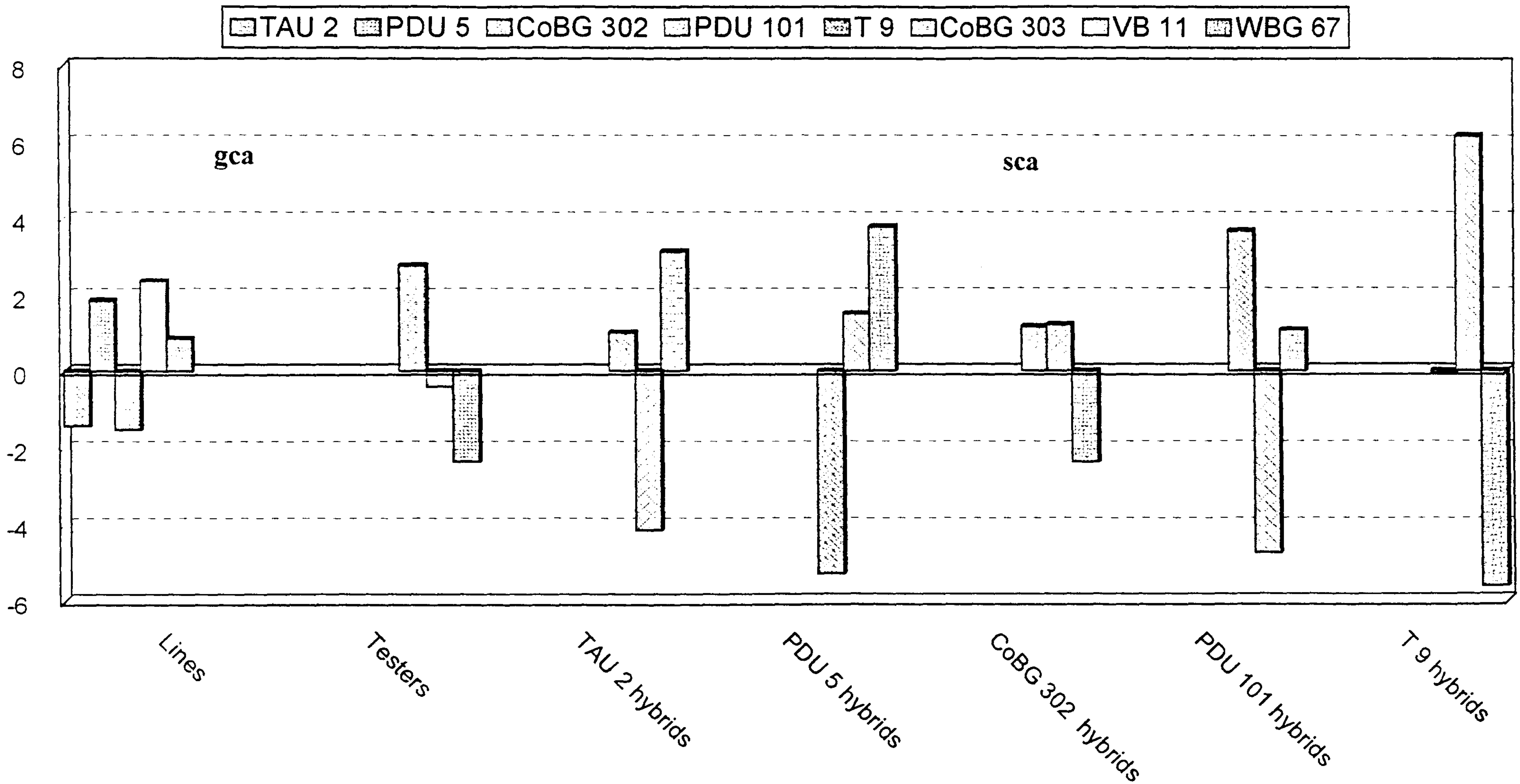


Fig. 4 General and specific combining ability for Leaf thickness



Among hybrids the cross TAU 2 x WBG 67 showed significant positive effect (0.033) while cross PDU 101 x WBG 67 showed significant negative effect (-0.034). Only four hybrids showed significant effects, and seven out of fifteen hybrids showed negative sca effects.

The ratio of variance due to gca to that due to sca was 0.025 when F = 0 (Table 7).

Stomatal distribution

As presented in Table 5a and Fig. 5 the line PDU 5 exhibited the highest positive and significant gca effects (1.858) for stomatal distribution. On the other hand CoBG 302 and TAU 2 showed negative significant gca effects of -1.520 and -1.431 respectively and were on par.

Among testers significant positive gca effect was shown by CoBG 303 (2.773) and significant negative effect by WBG 67 (-2.360).

Among hybrids highest positive significant sca was shown by T 9 x VB 11 (6.169) which was significantly different from all other hybrids. The hybrids T 9 x WBG 67, PDU 101 x VB 11, TAU 2 x VB 11 and COBG 302 x WBG 67 showed significant negative sca effects and were on par. The ratio of variance due to gca to that due to sca was 0.016. (Table 7).

Root shoot ratio

Regarding root shoot ratio at harvest the lines PDU 5 (0.019) and T 9 (0.005) had positive values, while negative values were shown by CoBG 302 (-0.013) and PDU 101 (-0.004).

The tester WBG 67 had positive gca for root shoot ratio (0.011) while tester CoBG 303 had negative gca (-0.010) effect.

Fig. 5 General and specific combining ability for stomata per microscopic field

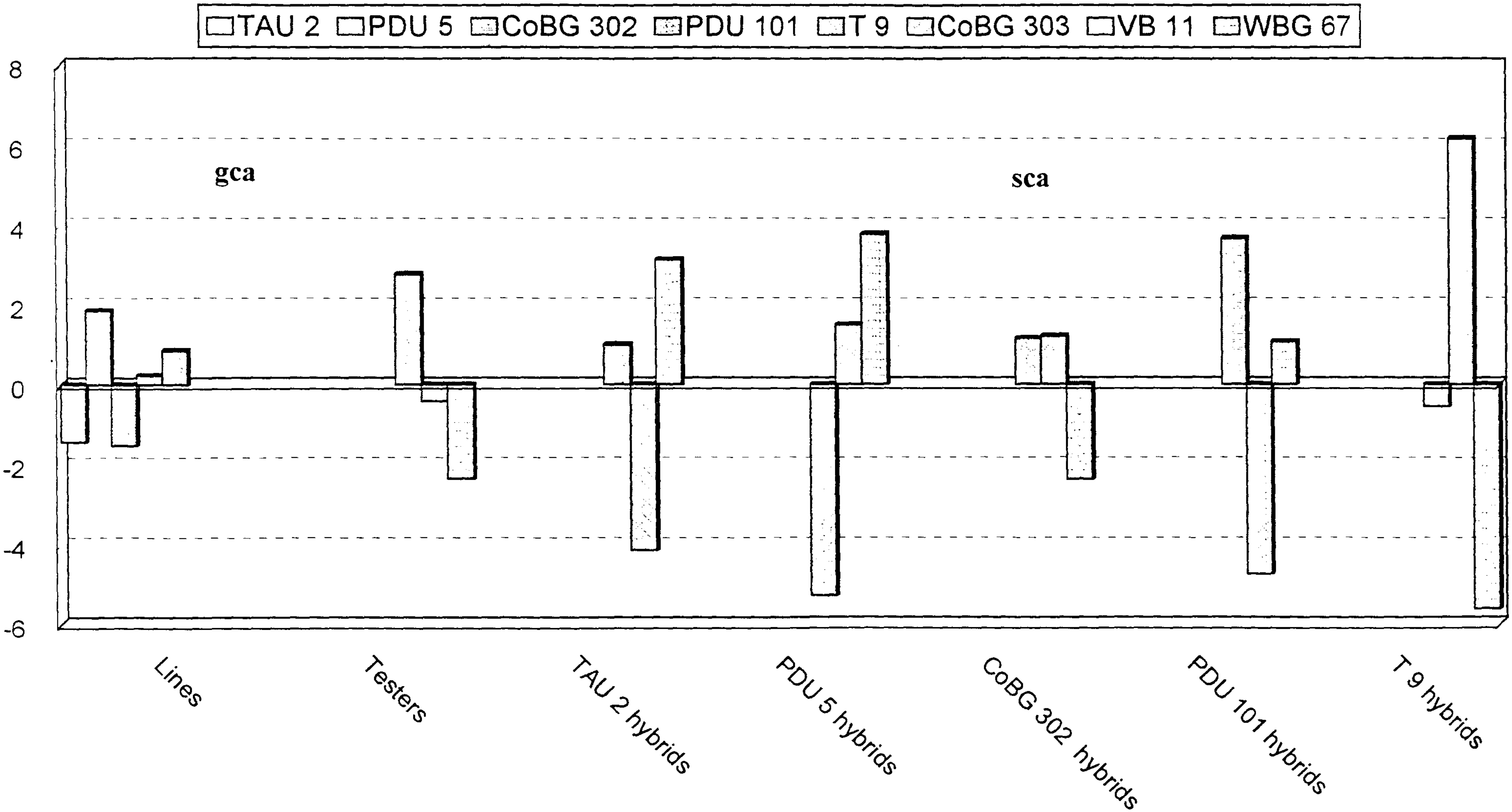
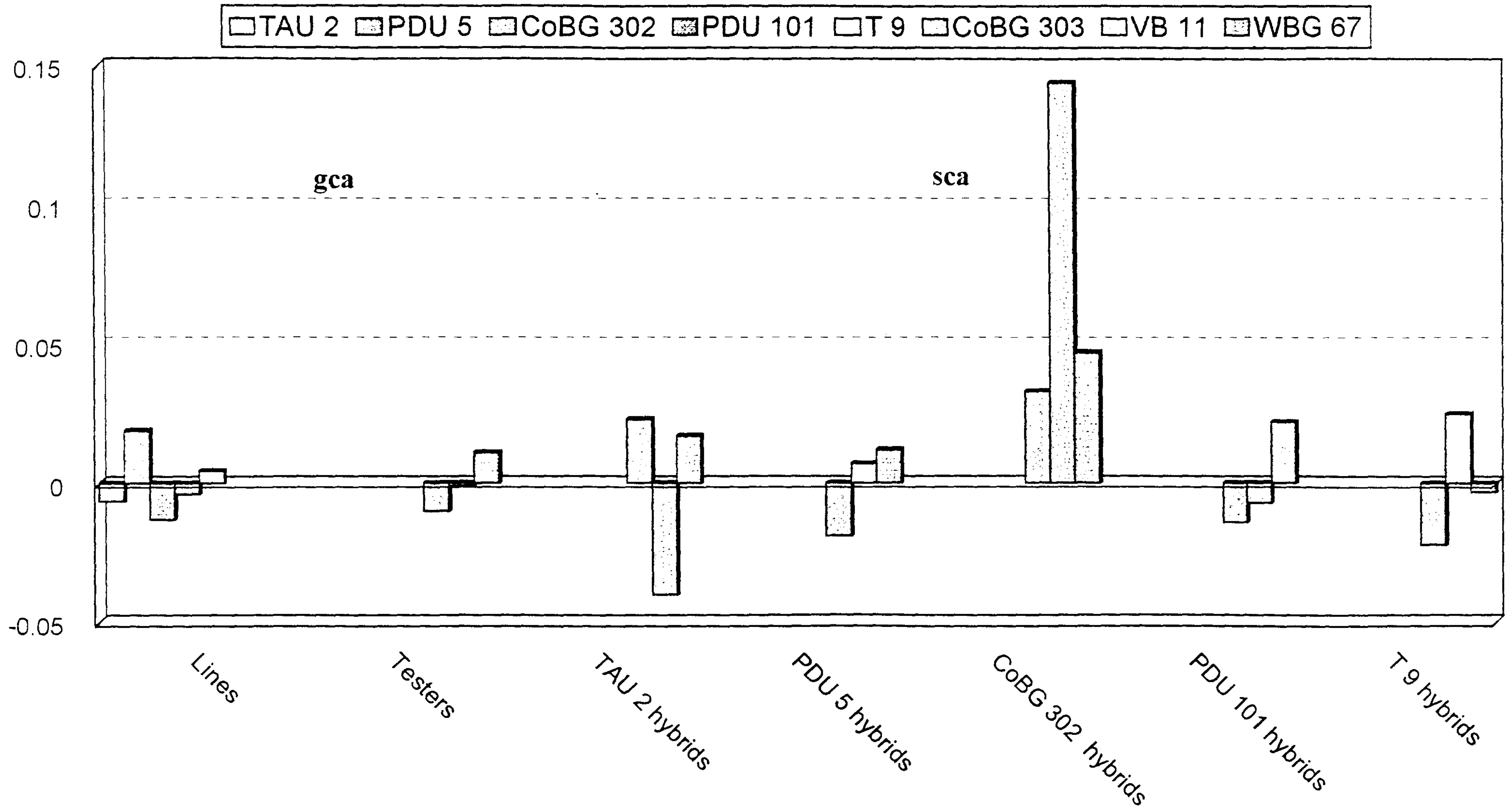


Fig. 6 General and specific combining ability for root shoot ratio



The cross CoBG 302 x CoBG 303 (0.033) showed the highest sca effect which was significant from all others. This was followed by crosses T 9 x VB 11 (0.025), TAU 2 x CoBG 303 (0.023) and PDU 101 x WBG 67 (0.022) which had positive values and were not significant. Highest negative sca effect was shown by the cross CoBG 302 x WBG 67 (-0.047) and was significantly different from other hybrids having negative sca effects. Seven out of fifteen crosses had negative sca effects. The gca and sca effects are depicted in Table 5a and Fig. 6. The ratio of variance due to gca to that due to sca was 0.025. (Table 7).

Root spread

The gca and sca effects for root spread at harvest time are presented in Table 5a and Fig. 7 . The gca effect of line CoBG 302 was found to be positive (7.40.) and significantly different from all other lines. Significant negative values were shown by PDU 101 (-4.83.) and PDU 5 (-3.49.) which were on par.

Among testers WBG 67 showed positive and significant gca value (2.34.) which was significantly different from the other two testers of which the gca effects were negative.

Five out of fifteen hybrids showed significant positive sca effects. Highest sca was shown by cross PDU 101 x WBG 67 (9.48.) and was on par with T 9 x VB 11 (8.37.). Significant positive values are also recorded by PDU 5 x CoBG 303 (4.63.) and CoBG 302 x CoBG 303 (4.47.) and were on par with each other. Highest negative value was shown by the cross PDU 101 x VB 11 (-6.39.) and was on par with T 9 x WBG 67 (-6.06.) both being

Fig. 7 General and specific combining ability for root spread

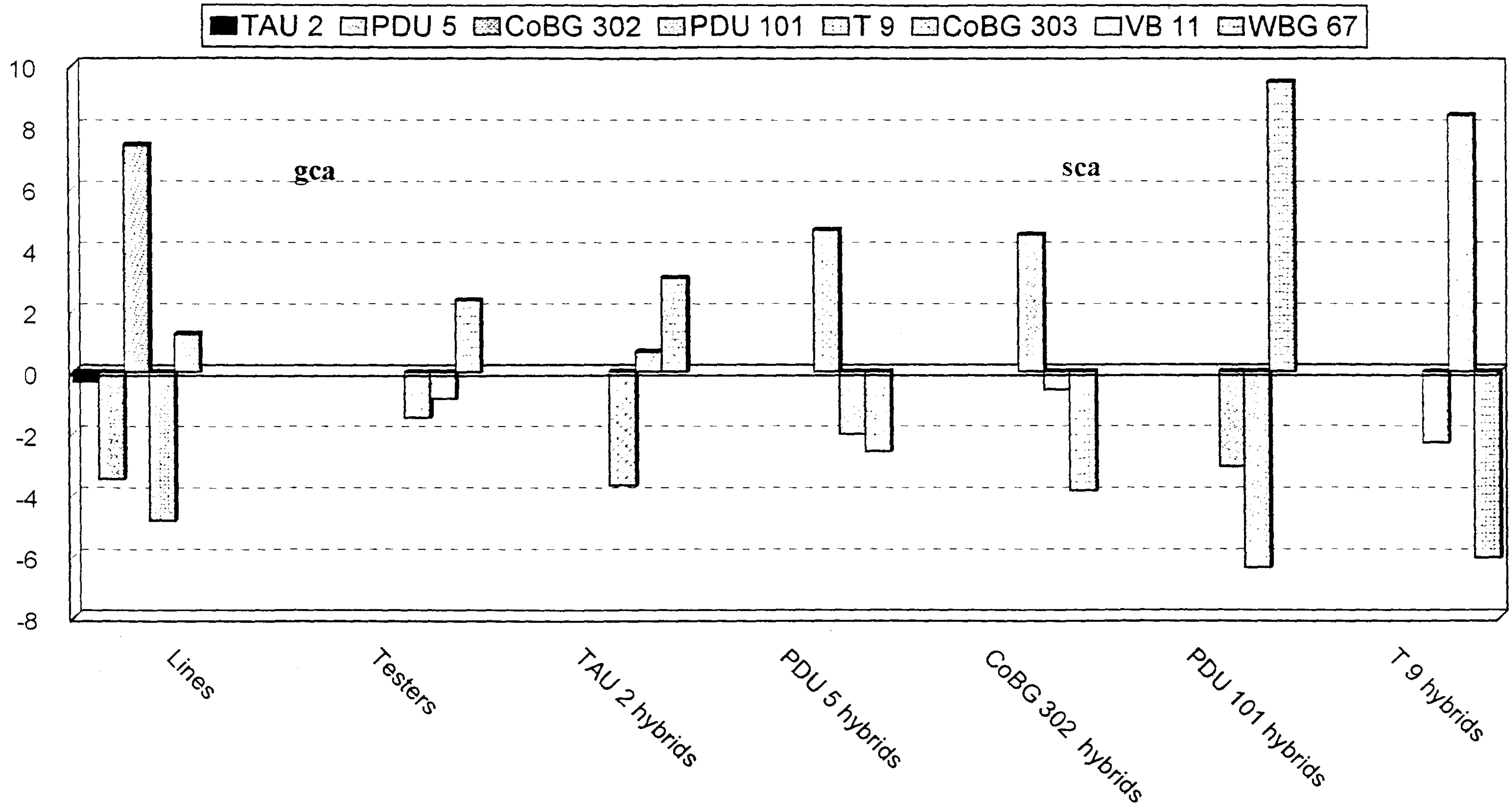


Table 5 b General and specific combining abilities for yield related characters

	Height of the plant (cm)	No. of branches per plant	No. of pods per plant	No. of seeds per pod	Grain yield per plant (g)	100 seed weight (g)	Seed protein (%)	Harvest index
Lines (gca)								
L_1 TAU 2	-3.989**	0.189	-6.86**	-0.398**	-2.156**	-0.039	-0.70**	-0.648**
L_2 PDU 5	6.100**	-0.522**	-7.37**	0.269**	-1.848**	0.159**	1.66**	0.036**
L_3 CoBG 302	-2.389	0.055	-0.75	-0.020	-0.956**	-0.139**	-1.75**	-0.062**
L_4 PDU 101	1.400	-0.111	-1.53	0.280**	-1.472**	0.296**	1.40**	-0.073**
L_5 T 9	-1.122	0.389*	16.52**	-0.131	6.431**	-0.276**	-0.60**	0.235**
SE	1.257	0.176	1.82	0.097	0.103	0.028	0.10	0.005
CD	3.584	0.501	5.19	0.275	0.294	0.080	0.29	0.014
Testers (gca)								
T_1 Co BG 303	-2.216**	0.011	-3.55**	-0.031	-0.324**	0.030	-0.44**	0.006
T_2 VB 11	1.391	-0.156	-0.28	-0.184*	-0.387**	-0.288**	1.63**	0.018**
T_3 WBG 67	0.824	0.144	3.83**	0.216**	0.712**	0.199**	-1.19**	-0.024**
SE	0.974	0.136	1.40	0.075	0.080	0.022	0.08	0.004
CD	2.777	ns	4.02	0.213	0.228	0.062	0.22	0.011
Hybrids (sca)								
L_1T_1	-0.851	0.144	4.84	-0.036	1.209**	0.137**	-0.98**	0.087**
L_2T_1	2.260	0.056	4.48	-0.569**	-0.369*	-0.442**	2.42**	0.055**
L_3T_1	3.749	-0.189	6.06	-0.280	2.592**	0.289**	2.12**	0.100**
L_4T_1	-3.240	0.244	-7.90*	0.387*	-4.12**	0.268**	-3.67**	-0.239**
L_5T_1	-1.918	-0.256	-7.48*	0.498**	0.689**	-0.253**	0.11	-0.003
L_1T_2	-1.991	-0.022	1.84	0.184	2.088**	0.448**	2.12**	0.075**
L_2T_2	1.253	0.089	1.28	0.518**	0.667**	0.213**	0.88**	-0.020*
L_3T_2	0.542	0.311	-3.68	0.207	-0.688**	0.131**	-0.93**	-0.034**
L_4T_2	-4.080	-0.822**	-6.10	-0.360*	1.035**	-0.810**	-1.21**	0.073**
L_5T_2	4.276*	0.444	6.66*	-0.549**	-3.102**	0.018	-0.86**	-0.094**
L_1T_3	2.842	-0.122	-6.67*	-0.149	-3.297**	-0.586**	-1.14**	0.162**
L_2T_3	-3.513	-0.144	-5.76	0.051	-0.298	0.229**	-3.30**	0.035**
L_3T_3	-4.291*	-0.122	-2.38	0.073	-1.904**	-0.420**	-1.19**	-0.066**
L_4T_3	7.320**	0.578	13.99**	-0.027	3.086**	0.542**	4.88**	0.165**
L_5T_3	-2.358	-0.189	0.818	0.051	2.413**	0.234**	0.75**	0.098**
SE	2.178	0.304	3.15	0.167	0.179	0.049	0.17	0.008
CD	6.208	0.868	8.98	0.477	0.509	0.139	0.49	0.024

* Significant at 5 % level ** Significant at 1 % level

significantly different from the other crosses. The crosses CoBG 302 x WBG 67 (-3.89) and TAU 2 x CoBG 303 (-3.71.) were also on par and recorded significant sca effects. The ratio of variance due to gca to that due to sca was 0.011 when inbreeding coefficient was zero (Table 7).

Proline content

The combining ability analysis of leaf proline content as shown in Table5a Fig. 8 showed that only T 9 had the significant positive gca effect of 98.66 among lines and significant negative value was shown only by CoBG 302 (-197.33).

In testers, VB 11 alone had significant positive gca effect (147.) while CoBG 303 had significant negative gca (-189.44).

Among hybrids the cross CoBG 302 x CoBG 303 (327.57) had the highest positive value which was significant and was on par with PDU 5 x WBG 67 (284.16) and PDU 101 x VB 11 (256.53). Significant positive value was also shown by T 9 x CoBG 303 (179.57) and TAU 2 x VB 11 (118.40). The highest negative and significant gca for proline content of leaves was shown by the cross PDU 101 x CoBG 303 (-323.63) which was on par with CoBG 302 x WBG 67 (-258.50) and PDU 5 x VB 11 (-177.59). In all, there were nine hybrids with negative sca effects out of fifteen. The ratio of gca variance to that due to sca was 0.005 when F = 0(Table 7).

Plant height

Table 5b and Fig 9. gives the combining ability effects for height of the plant. The gca effects of lines were found to differ significantly. Among lines, TAU 2 had maximum negative gca (-3.989) and was on par with gca effects of

Fig. 8 General and specific combining ability for proline content

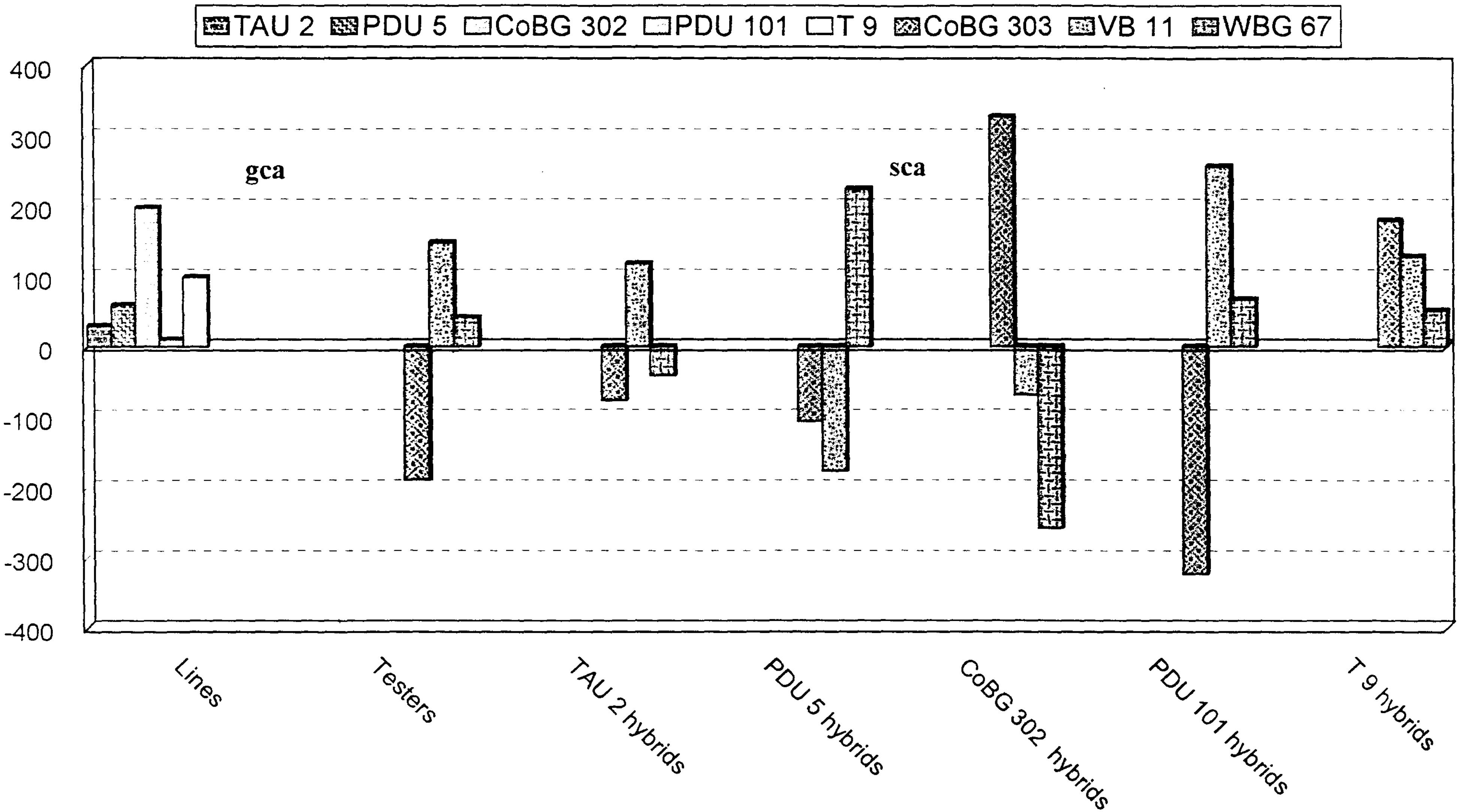
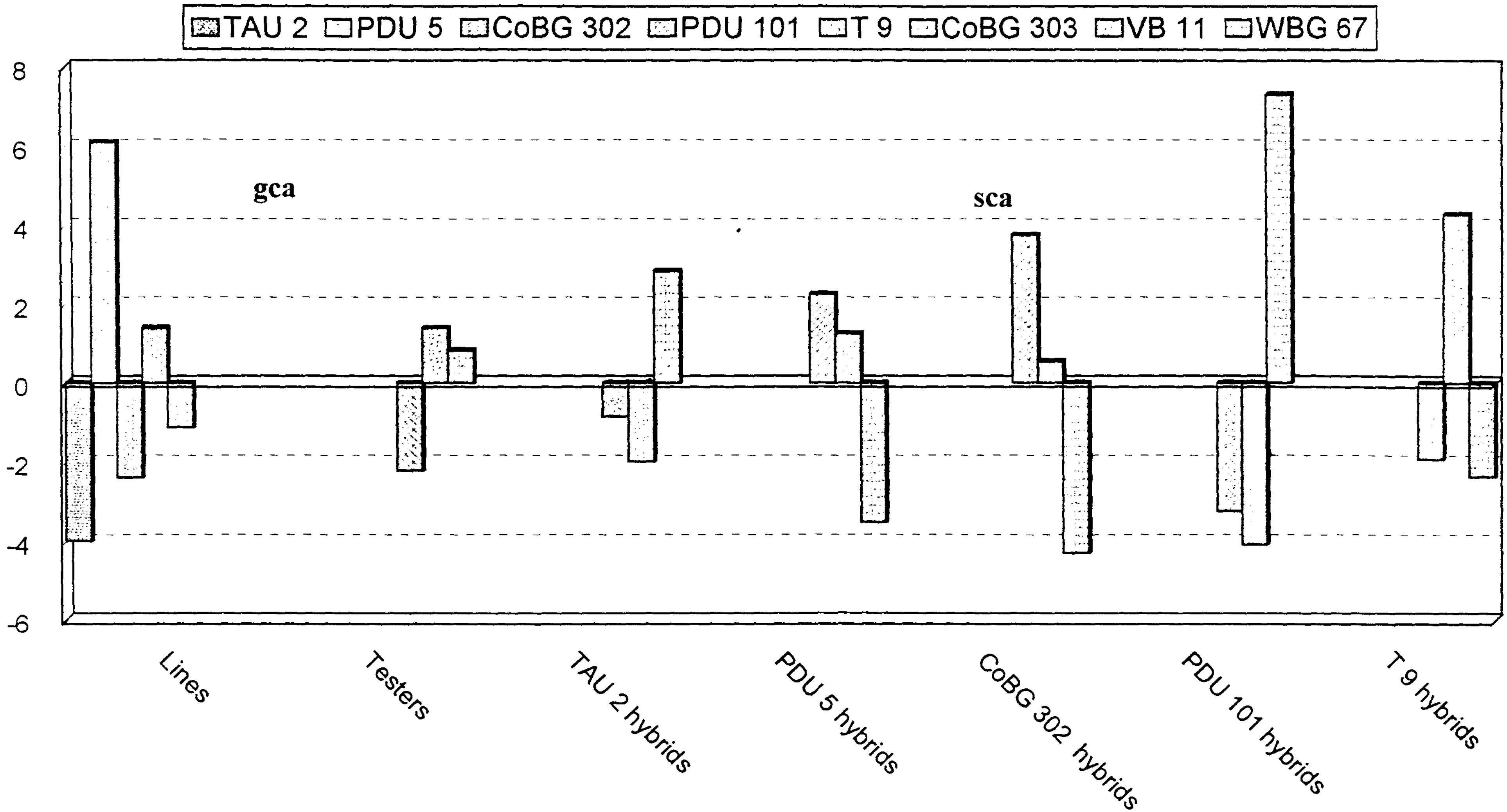


Fig. 9 General and specific combining ability for height of the plant



CoBG 302 (-2.389) and T 9 (-1.122). Positive significant gca effect was shown by PDU 5 (6.100) which was statistically superior to PDU 101 (1.400).

Among testers CoBG 303 had negative gca effect (-2.216) and was significant at 1% while the other two showed positive effects.

Eight out of fifteen hybrids had negative sca ranging from -4.291 for CoBG 302 x WBG 67 to -0.851 for TAU 2 x CoBG 303. Maximum positive sca effect was shown by the cross PDU 101 x WBG 67 (7.320) and this significantly differed from all the other crosses at 1% level of significance. Among other crosses T 9 x VB 11 and CoBG 302 x WBG 67 were significant at 5% level with respect to the sca effects for this character.

The ratio of variance due to gca to that due to sca was less than one (0.042) when inbreeding coefficient (F) was zero (Table 7).

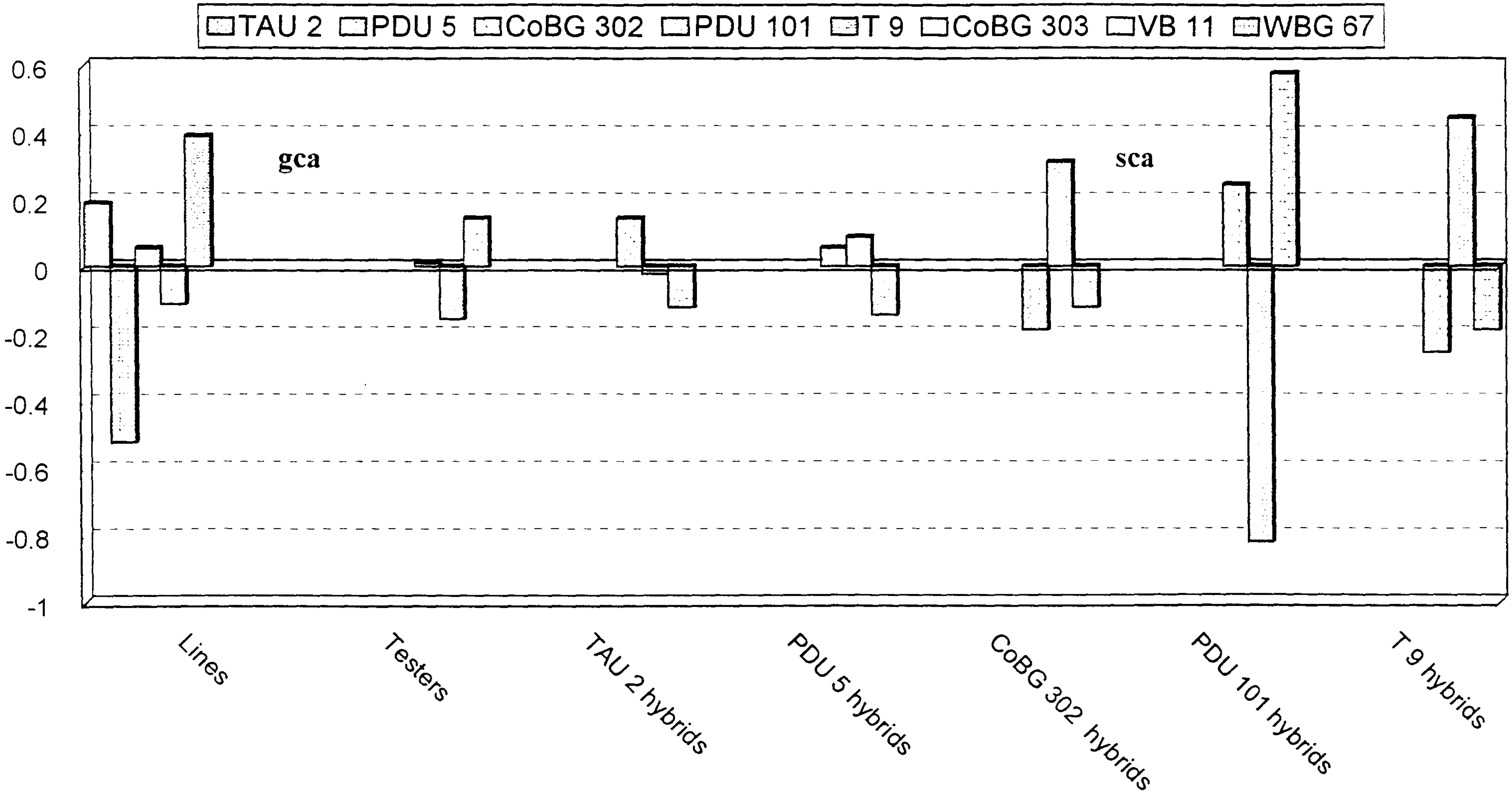
Number of branches per plant

The general and specific combining abilities of number of branches per plant are presented in Table 5b and Fig. 10. Lines differed significantly with respect to gca effects for number of branches per plant. Maximum positive gca effect was shown by T 9 (0.389). The line PDU 5 had maximum negative gca effect (-0.522) which was significantly different from all others except PDU 101.

All the testers were on par with respect to the gca effect for the character. Only VB 11 showed negative gca effect while the other two showed positive effects.

Hybrids too did not differ significantly with respect to sca for number of branches per plant. The cross PDU 101 x WBG 67 had maximum positive sca

Fig. 10 General and specific combining ability for number of branches / plant



effects (0.578) whereas PDU 101 x VB 11 showed maximum negative effect (-0.822). Seven out of fifteen crosses had positive sca effects. The ratio of variance due to gca and sca was less than one (0.033) when inbreeding coefficient (F) was zero (Table 7).

Number of pods per plant

Lines differed significantly with respect to gca effects for number of pods per plant (Table 5b and Fig. 11). The line T9 had significant positive gca effect (16.516) which was significantly different from all other lines which showed negative effects. Significant negative value for gca was shown by PDU 5.(-7.373) followed by TAU 2 (-6.862) which were on par and significantly differed from other two lines.

The tester WBG 67 showed maximum positive gca effect (3.83) while CoBG 303 had maximum negative effect (-3.55).

The hybrid PDU 101 x WBG 67 exhibited maximum positive sca effect (13.99) which was significant. The cross PDU 101 x CoBG 303 showed maximum negative sca effect (-7.90) for the character. Seven out of fifteen crosses had negative sca effects. The ratio of variance due to gca to that due to sca was 0.101 when inbreeding coefficient (F) was equal to zero (Table 7).

Number of seeds per pod

The gca and sca effects of number of seeds per pod are presented in Table 5b and Fig. 12. The line PDU 101 had significant positive gca (0.280) and TAU 2 significant negative gca (-0.398). Significant positive gca (0.216) was shown only by the tester WBG 67 while the maximum negative effect was shown by the tester VB 11 (-0.184) and was significant at 5%.

Fig. 11 General and specific combining ability for number of pods / plant

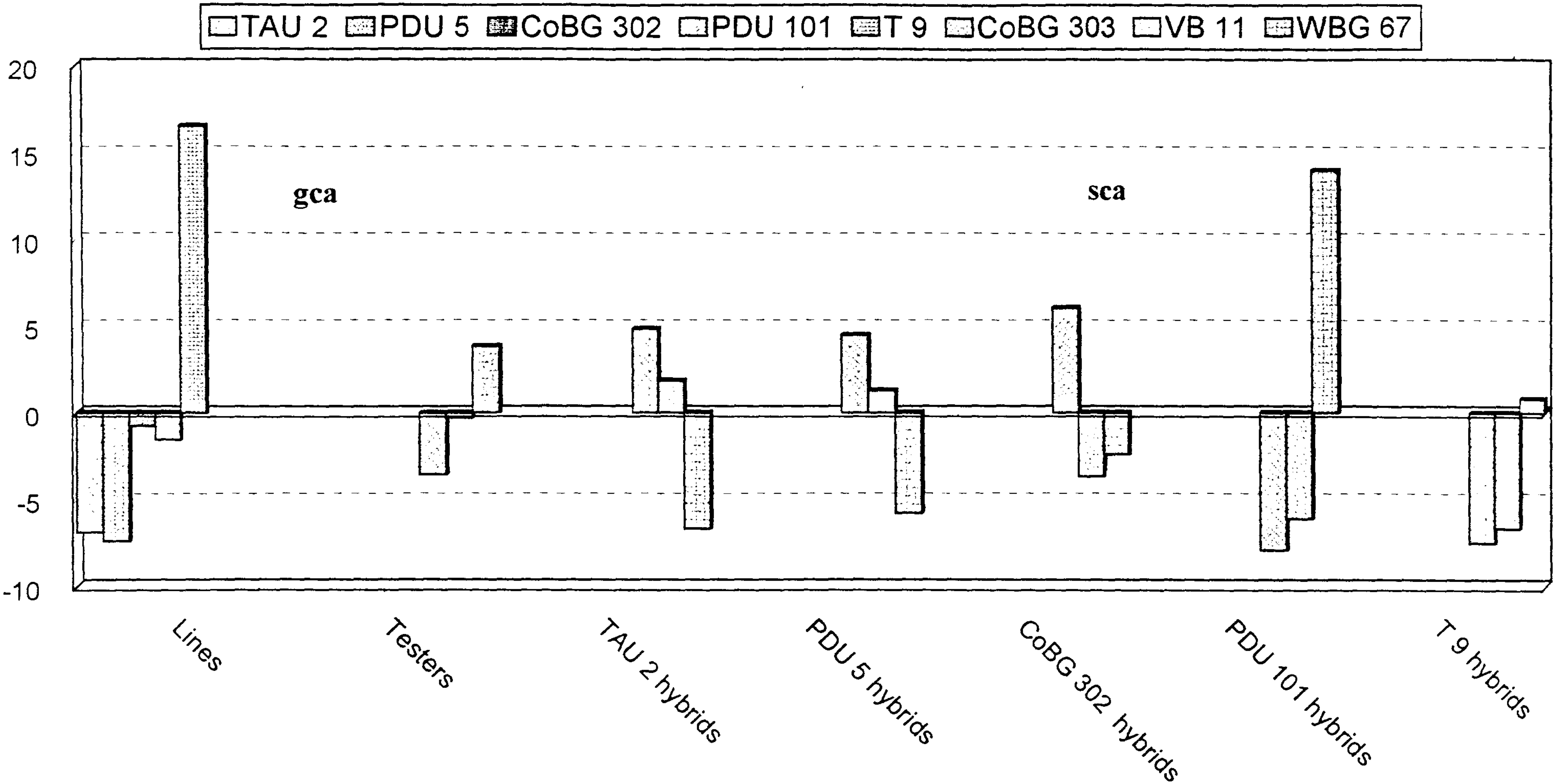
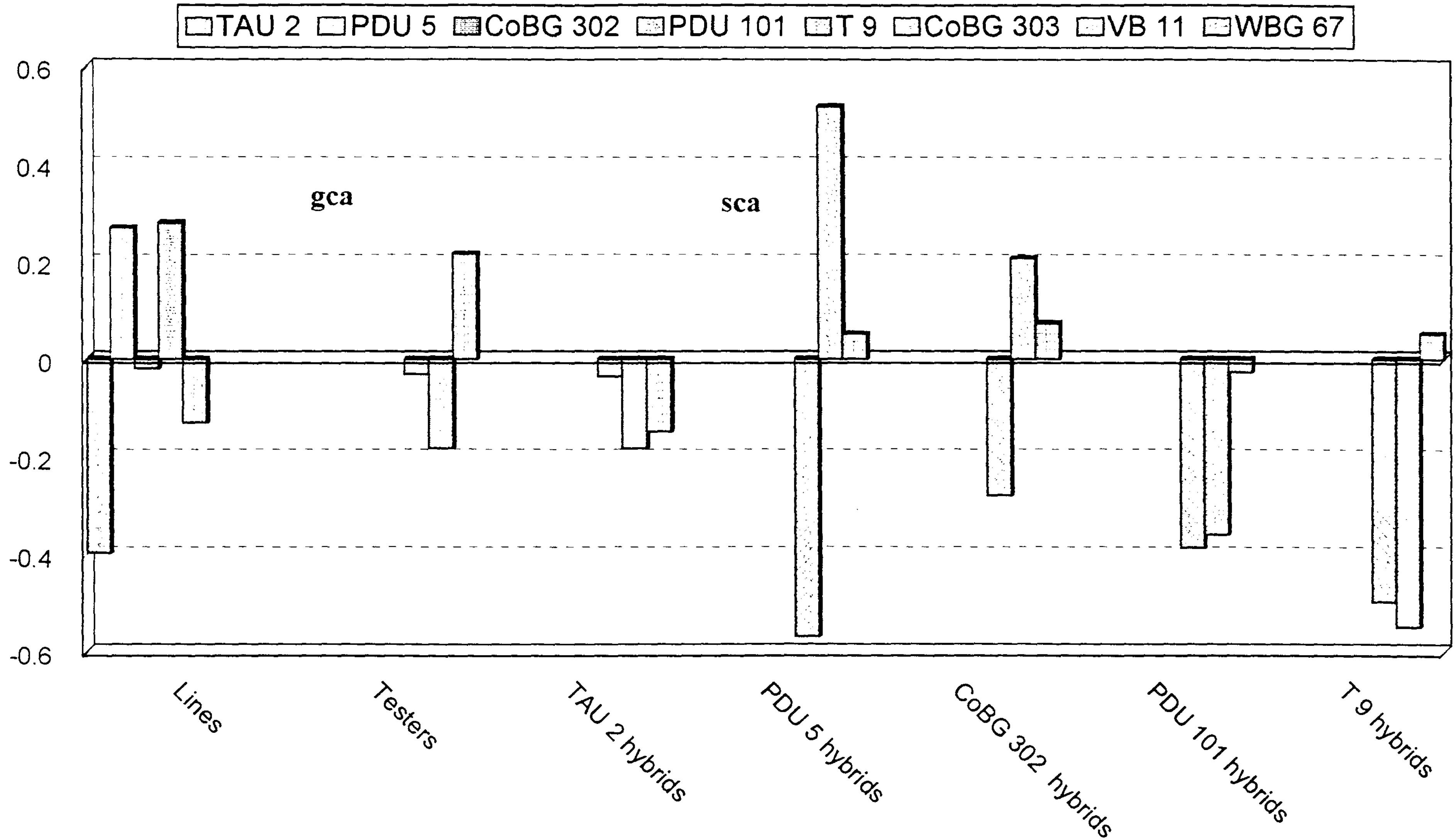


Fig. 12 General and specific combining ability for number of seeds / pod



Eight out of fifteen crosses had positive sca effect. Maximum positive sca effect was shown by PDU 5 x VB 11 (0.518) which was on par with T9 x CoBG 303 (0.498). Significant negative sca effect was shown by PDU 5 x CoBG 303 (-0.569) followed by the cross T 9 x VB 11 (-0.549). The ratio of variance due to gca to that due to sca was less than one (0.008) when inbreeding coefficient (F) was zero (Table7).

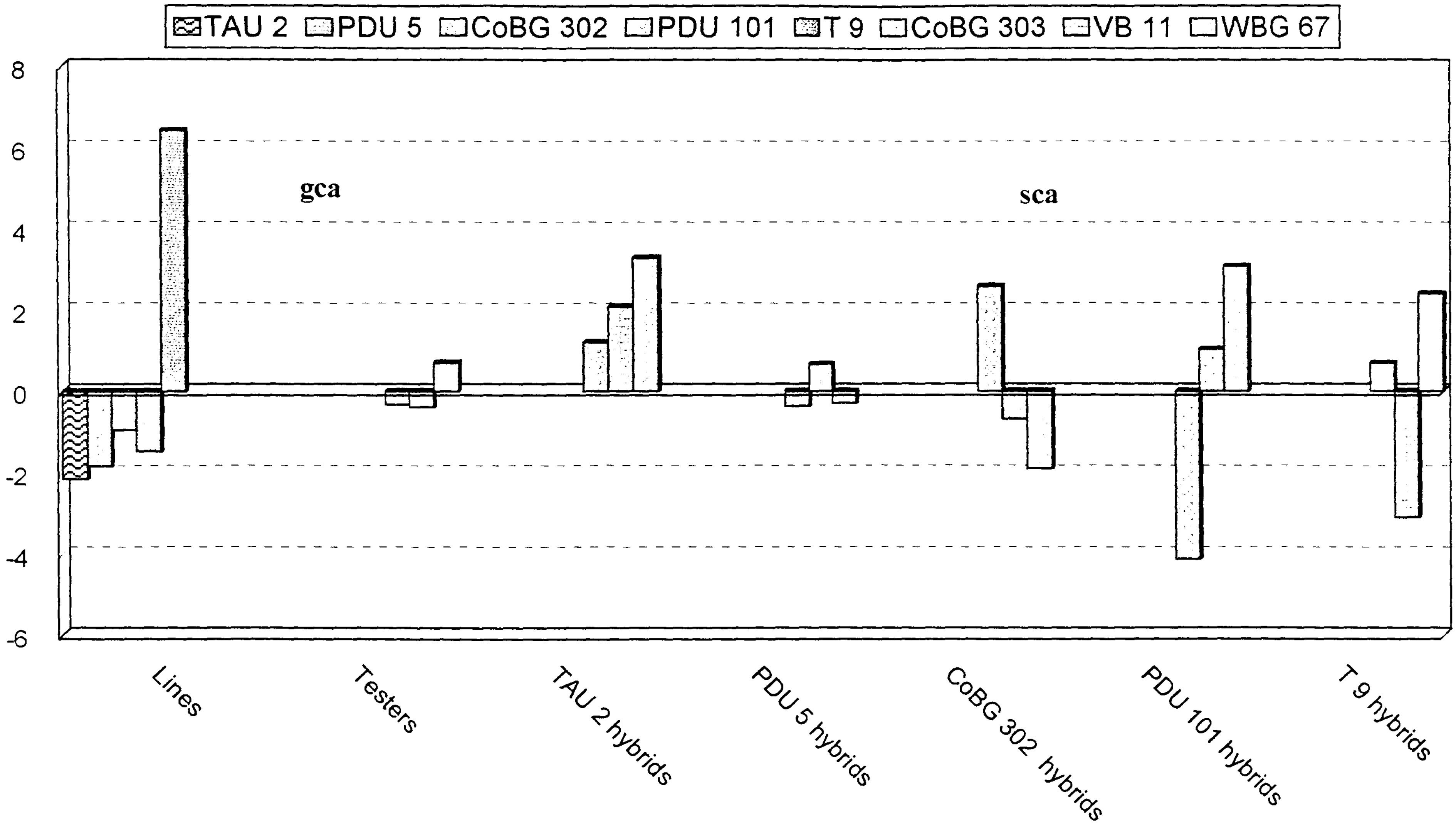
Grain yield per plant

The combining ability analysis for grain yield per plant showed significant gca effects for both lines and testers as shown in the Table 5b and Fig. 13. Among lines T 9 showed positive and significant gca (6.431) which was significantly different from all other lines. All other lines showed significant and negative gca effects with TAU 2 showing maximum effect (-2.156) among them.

All the testers showed significant values for gca. WBG 67 had positive gca effect (0.712) and the other two showing negative effects.

Among hybrids all the crosses except two were found to be significant. The sca effects of the crosses PDU 101 x WBG 67 (3.086) and CoBG 302 x CoBG 303 (2.592) were on par and showed the highest sca compared to the other crosses. The crosses T9 x WBG 67 (2.413) and TAU 2 x VB 11 (2.088) were also significant and on par. Eight out of 15 crosses showed positive effects. Significant negative sca effect shown by PDU 101 x CoBG 303 (-4.121) was maximum. The ratio of variance due to gca to sca was less than one (0.091) when the value of F was zero (Table 7).

Fig. 13 General and specific combining ability for grain yield / plant



Hundred seed weight.

The general and specific combining ability effects for hundred seed weight are presented in Table 5b and Fig. 14. Among lines PDU 101 (0.296) had significant positive gca effect which was significantly different from all others, PDU 5 also had significant positive effect (0.159). The significant negative gca were shown by T 9 (-0.276) and CoBG 302 (-0.139).

Two of the testers had positive gca effects of which WBG 67 had significant effect (0.199). Only VB 11 recorded negative effect which was significant (-0.228).

Significant positive sca effects were exhibited by the cross PDU 101 x WBG 67 (0.542) and TAU 2 x VB 11 (0.448) which were on par. Highest negative sca was shown by the cross PDU 101 x VB 11 (-0.81) which was significantly different from all others with negative sca effects. Five of the crosses showed negative values for sca which were all significant. The ratio of variance due to gca to that due to sca was 0.016 when the value of inbreeding coefficient (F) was zero (Table 7).

Seed protein content

Table 5b and Fig. 15 represents the gca and sca effects of parents and crosses for seed protein content. Among lines significant positive gca effect was shown by the line PDU 5 (1.66) and was on par with PDU 101 (1.40). Significant negative gca was shown by CoBG 302 (-1.75) and was significantly different from other lines with negative gca effects. TAU 2 with gca effect -0.70 and T 9 with -0.60 were also negative and significant.

Among testers positive significant gca was shown by VB 11 (1.63) and

Fig. 14   General and specific combining ability for hundred seed weight

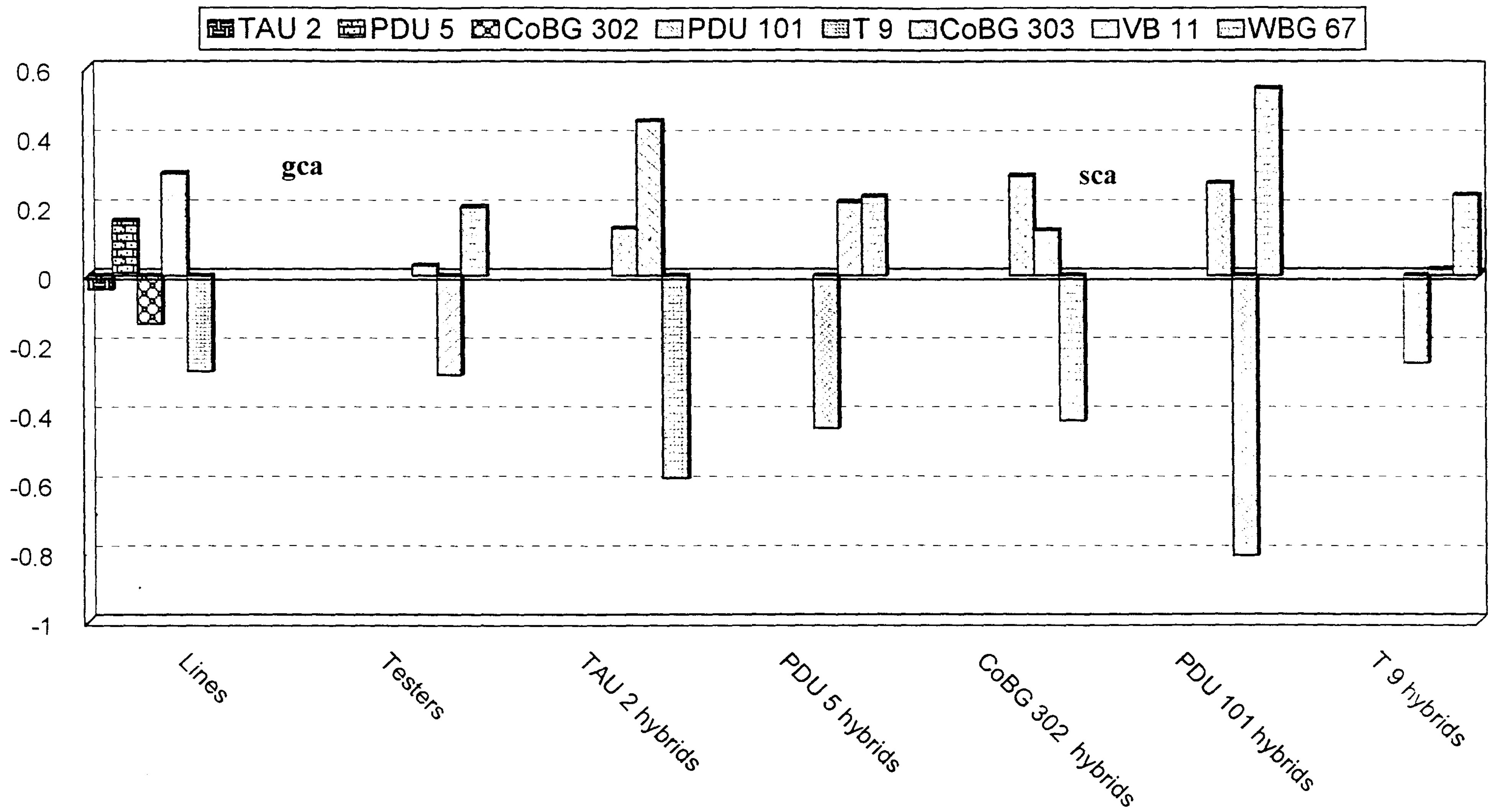
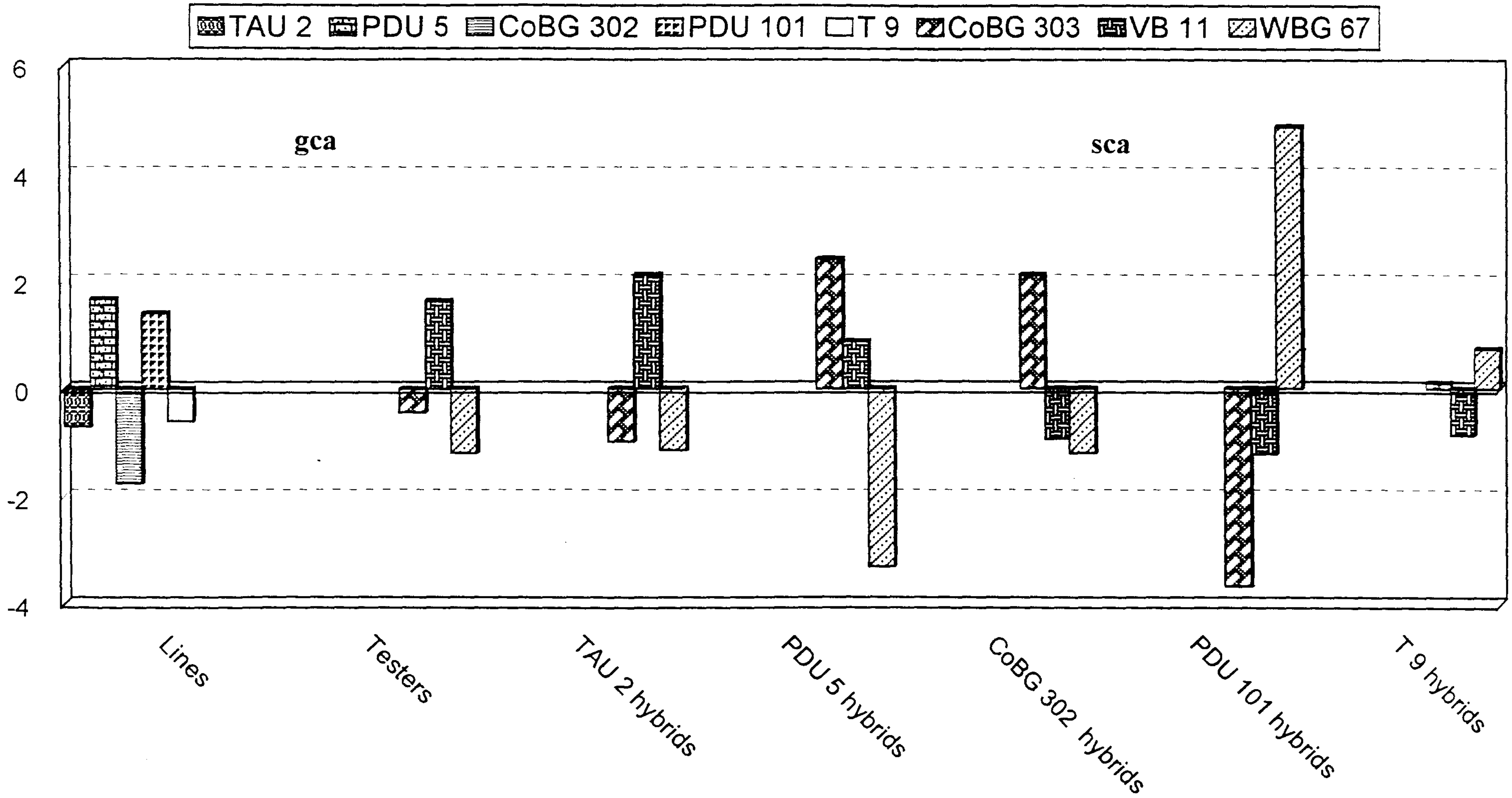


Fig. 15 General and specific combining ability for seed protein content



significant negative gca by WBG 67 (-1.19) CoBG 303 also recorded significant negative gca effect (-0.44).

All the hybrids except T 9 x CoBG 303 exhibited significant sca effects with respect to the character. The cross PDU 101 x WBG 67 (4.88) showed positive and significant sca which was significantly different from all other hybrids. Six hybrids out of fifteen showed significant positive gca of which PDU 5 x CoBG 303 (2.42), CoBG 302 x CoBG 303 (2.12) and TAU 2 x VB11 (2.12) were on par. Highest negative sca was shown by the cross PDU 101 x CoBG 303 (-3.69) and was on par with PDU 5 x WBG 67 (-3.30). Eight out of fifteen hybrids showed negative sca effects which were all significant.

Ratio of variance due to gca to that due to sca was 0.005 when the value of (F) was zero (Table 7).

Harvest Index

The general and specific combining abilities for harvest index are presented in Table 5b and Fig. 16 . All the lines had significant gca effects. Highest positive gca value was recorded by T 9 (0.235) which was significantly different PDU 5 (0.036). The other three lines had significant negative values with highest for PDU 101 (-0.073).

Among testers VB 11 had significant positive gca (0.018) while WBG 67 (-0.024) had significant negative gca effects.

Among crosses seven had significant positive sca with PDU 101 x WBG 67 showing the maximum value (0.165) and was significantly different from all others. The crosses CoBG 302 x CoBG 303 (0.100), T 9 x WBG 67

Fig. 16 General and specific combining ability for harvest index

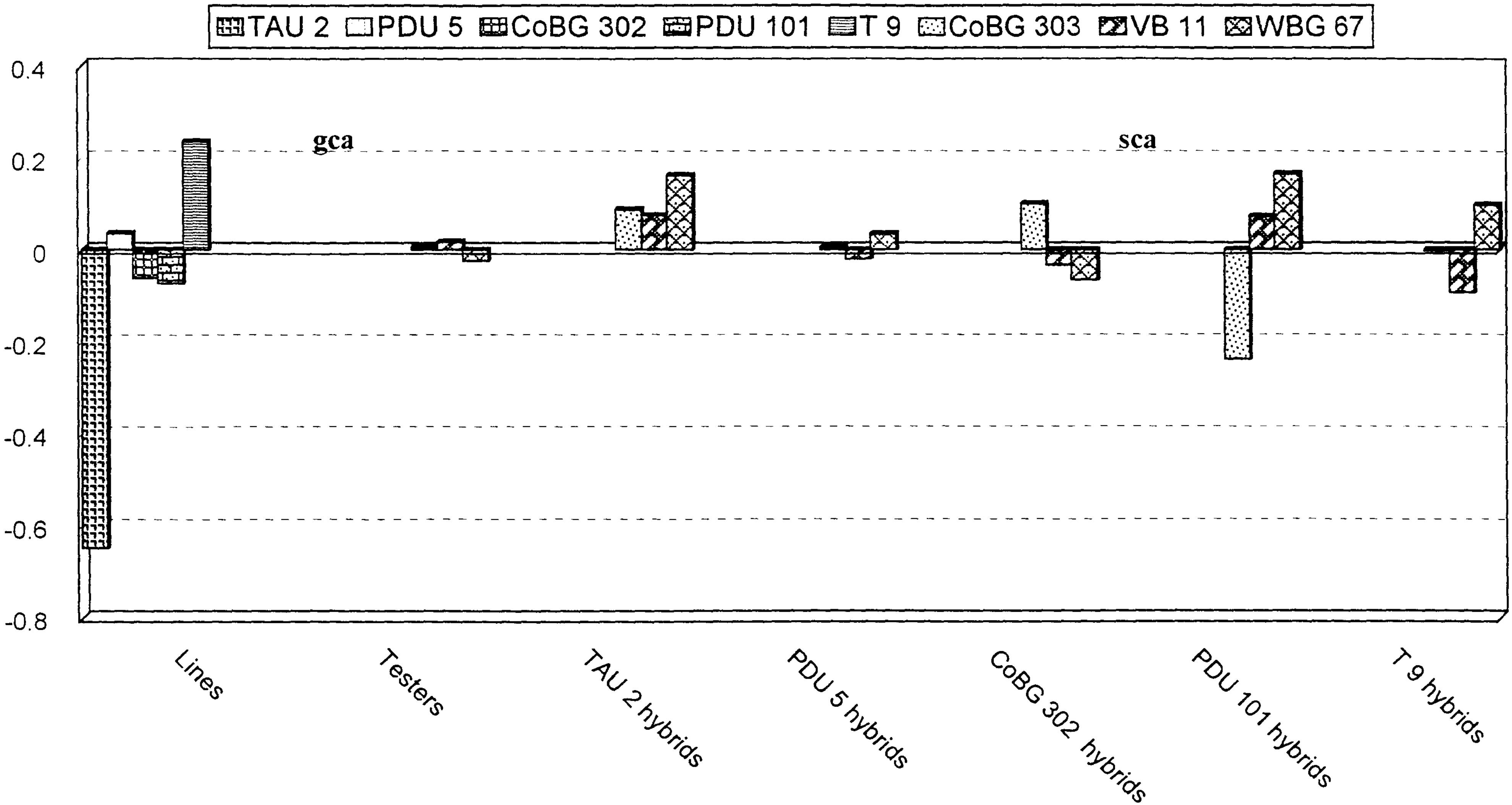


Table 6. Proportional Contribution of lines, testers and crosses

Sl. No		Lines	Testers	Crosses
1	Days to 50 % flowering	9.90	7.58	82.52
2	Duration of the crop	90.89	0.72	8.39
3	Leaf area index	20.48	30.23	49.29
4	Leaf thickness	39.70	12.28	48.02
5	Stomata / microscopic field	9.19	23.91	66.90
6	Root shoot ratio	15.85	9.66	74.49
7	Spread of root	41.69	6.36	51.95
8	Proline content	15.83	29.53	54.64
9	Height of the plant	46.94	9.39	43.67
10	Number of branches / plant	44.06	6.98	48.96
11	Number of pods / plant	61.28	7.39	31.33
12	Number of seeds / pod	32.69	13.59	53.72
13	Grain yield / plant	67.60	1.63	30.77
14	100 seed weight	18.71	13.75	67.54
15	Seed protein content	21.85	18.12	60.03
16	Harvest index	54.83	1.24	43.93

Table 7. **Ratio of variance due to gca to variance due to sca when inbreeding coefficient (F) = 0**

Sl.No	Characters	σ^2 gca	σ^2 sca	σ^2 gca / σ^2 sca
1	Days to 50 % flowering	1.125	34.467	0.033
2	Duration of the crop	2.567	3.984	0.644
3	Leaf area index	0.048	2.823	0.017
4	Leaf thickness	0.00001	0.0005	0.025
5	Stomata / microscopic field	0.364	22.812	0.016
6	Root shoot ratio	0.00003	0.001	0.025
7	Spread of root	0.456	41.483	0.011
8	Proline content	333.943	66481.4	0.005
9	Height of the plant	0.714	16.857	0.042
10	Number of branches / plant	0.004	0.105	0.033
11	Number of pods / plant	6.319	62.362	0.101
12	Number of seeds / pod	0.001	0.173	0.008
13	Grain yield / plant	0.815	8.928	0.091
14	100 seed weight	0.005	0.282	0.017
15	Seed protein content	0.041	8.857	0.005
16	Harvest index	0.0006	0.021	0.032

(0.098) and TAU 2 x CoBG 303 (0.087) were on par with significant positive effects. The highest negative sca was shown by PDU 101 x CoBG 303 (-0.239) which was significantly different from other crosses with negative sca effects. All crosses except T 9 x CoBG 303 had significant sca effects. The ratio of gca variance to sca variance was 0.032 when inbreeding coefficient (F) was zero (Table 7).

Proportional contribution

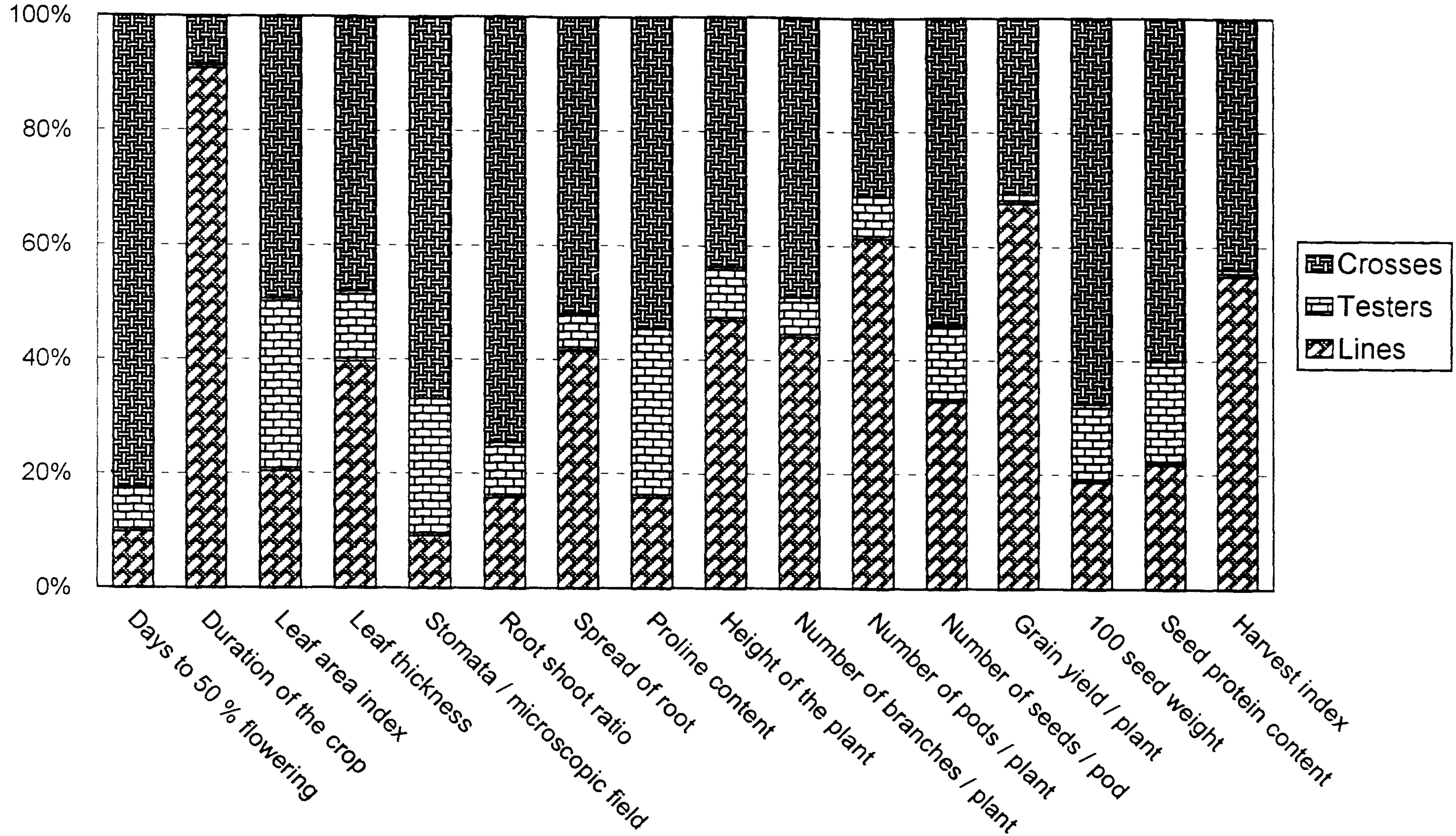
The proportional contribution of lines, testers and line x tester to the total variance for different characters are presented in the Table 6 and Fig 17.. The proportional contribution of lines, testers and crosses to the total variance of the characters under study had a range of 9.19 for stomata per microscopic field to 90.89 for duration of the crop among lines. Among testers the values ranged from 0.72 for duration of the crop to 30.23 for leaf area index. In the case of crosses the values ranged from 8.394 duration of the crop to 82.52 for days to 50 per cent flowering.

Among the lines, the propotional contribution to total variance was maximum for the characters, duration of the crop (90.89), seed yield per plant (67.60), number of pods per plant (61.28), harvest index (54.83) and height of the plant (46.94)and the contribution was minimum for root shoot ratio (15.85), free proline content of the leaves (15.83), days to 50 per cent flowering (9.90) and stomata per microscopic field (9.19).

In general the contribution of testers was less. The characters which had more contributions from testers were leaf area index (30.23), proline content (29.53) and stomata per microscopic field (23.91). The contribution of testers were negligible for the characters seed yield per plant (1.63), harvest index (1.24) and duration of crop (0.72).

Hybrids had comparatively more contributions towards the total variance with respect to most characters with a lone exception of duration of the crop for which the hybrids contributed only 8.39 per cent. Contribution of hybrids to the total variance was high for the characters days to 50 per cent flowering (82.52), root shoot ratio (74.49), hundred seed weight (67.54), stomata per microscopic field (66.90) and seed protein (60.03).

Fig. 17 Proportional contribution of lines, testers and crosses



Tabe 8. **Best line, tester and cross for various characters based on combining ability**.

Sl. No.	Character	Best line	Best tester	Best cross
1	Days to 50% flowering	T 9	CoBG 303	PDU 101 x WBG 67
2	Duration of the crop	T 9	WBG 67	PDU 101 x WBG 67
3	Leaf area index	CoBG 302	WBG 67	PDU 5 x WBG 67
4	Leaf thickness	T 9	VB 11	TAU 2 x WBG 67
5	Stomata / microscopic field	CoBG 302	WBG 67	T 9 x WBG 67
6	Root shoot ratio	PDU 5	WBG 67	CoBG 302 x CoBG 303
7	Spread of root	CoBG 302	WBG 67	PDU 101 x WBG 67
8	Proline content	T 9	VB 11	CoBG 302 x CoBG 303
9	Height of the plant	PDU 5	VB 11	PDU 101 x WBG 67
10	Number of branches / plant	T 9	WBG 67	PDU 101 x WBG 67
11	Number of pods / plant	T 9	WBG 67	PDU 101 x WBG 67
12	Number of seeds / pod	PDU 101	WBG 67	PDU 5 x VB 11
13	Grain yield / plant	T 9	WBG 67	PDU 101 x WBG 67
14	100 seed weight	PDU 101	WBG 67	PDU 101 x WBG 67
15	Seed protein content	PDU 5	VB 11	PDU 101 x WBG 67
16	Harvest index	T 9.	VB 11	PDU 101 x WBG 67

Table 9. **Combination of parents for various yield and drought characters based on combining ability**

	TAU 2	PDU 5	COBG 302	PDU 101	T 9
CoBG 303	Days to 50 % flowering Duration of the crop Grain yield per plant 100 seed weight Harvest Index	Duration of the crop Root spread Seed protein content Harvest index	Days to 50 % flowering Leaf area index Root shoot ratio Root spread Proline content Grain yield / plant 100 seed weight Seed protein content Harvest index	Leaf thickness Number of seeds / pod 100 seed weight	Proline content Number of seeds / pod Grain yield / plant
VB 11	Leaf area index Stomata / microscopic field Proline content Grain yield / plant 100 seed weight Seed protein content Harvest index	Days to 50 % flowering Number of seeds / pod Grain yield / plant 100 seed weight Seed protein content	Number of pods / plant 100 seed weight	Leaf area index Stomata / microscopic field Proline content Grain yield / plant Harvest index	Days to 50 % flowering Leaf area index Leaf thickness Root spread Height of the plant Number of branches / plant Number of pods / plant 100 seed weight
WBG 67	Leaf area index Leaf thickness Root spread	Proline content 100 seed weight	Stomata / microscopic field	Days to 50 % flowering Duration of the crop Leaf area index Root spread Height of the plant Number of branches / plant Number of pods / plant Grain yield / plant 100 seed weight Seed protein content Harvest index	Stomata / microscopic field Grain yield / plant 100 seed weight Seed protein content Harvest index

DISCUSSION

5. DISCUSSION

The selection of suitable parents for hybridization is one of the most important steps in a hybridization programme. Selection of parents on the basis of phenotypic performance alone is not scientific since phenotypically superior lines may yield poor recombinants in the seggregating generations. Information on combining ability is helpful in selecting materials for the recombination breeding or population breeding programme. Sprague and Tatum (1942) attributed general combining ability (gca) of parents to additive gene action and specific combining ability (sca) of hybrids to dominance deviation and epistatic interaction.

The commonly used methods to estimate gca, sca and gene action are diallel analysis and line x tester analysis. The line x tester analysis proposed by Kempthorne (1957) has some advantages over diallel analysis. Line x tester analysis avoids the interaction among males and females. It has lower number of cross combinations compared to diallel analysis without affecting reliability of the information required. It is very helpful in self pollinated crops like blackgram where artificial hybridization is difficult.

In the present research work, analysis of variance showed that all the treatment mean squares were significant for all the characters suggesting that there existed significant differences among the treatments. The parents differed significantly for all the traits except number of branches per plant and number of pods per plant. All the crosses were found to differ significantly for all the sixteen characters (Table 4.a and 4.b). Therefore these characters were subjected to line x tester analysis inorder to estimate combining ability and gene action. All the parents and crosses were found to be medium hairy.

5.1 Duration upto 50 per cent flowering

Early flowering helps crop to escape from the effects of drought by completing the life cycle early before the advent of drought. So varieties with short lifespan are preferred under drought conditions. Early flowering is an indication of short duration of the crop. Variance for duration upto 50 per cent flowering showed that line x tester varies significantly whereas the variance due to lines and testers did not. Thus sca variance was found to be significant for this character suggesting nonadditive gene action (Table 4.a). The ratio of gca variance to sca variance was less than one which confirms the predominance of nonadditive gene action (Table 7).

Nonadditive gene action for 50 per cent flowering was reported by Deshmukh and Manjare (1980) in greengram, Mandal and Bhal (1987) and Jahagirdar *et al.* (1994) in chickpea, Katiyar *et al.* (1987) in pea, Thiyagarajan *et al.* (1990) in cowpea. However significance of both gca and sca effects with a predominance of nonadditive gene action was reported by Kumar (1993) in cowpea and predominance of additive gene action was reported by Durong (1980) in soybean, Dubey and Lal (1983) in pea, Dhillon and Chahal (1981) in garden pea, Venkateswarlu and Singh (1981a), Cheralu *et al.* (1989) and Saxena *et al.* (1989) in pigeonpea, Wilson *et al.* (1985) and Naidu and Satyanarayana (1993) in greengram, Patil and Bhapkar (1986) and Rejatha (1992) in cowpea and Katiyar *et al.* (1988) in chickpea.

Among lines T 9 and TAU 2 had significant negative gca, while CoBG 303 and WBG 67 among testers had significant negative gca (Table 5.a).

Maximum negative sca effect was shown by the cross PDU 101 x WBG 67. Parents with positive gca among lines and negative gca among testers were involved in this cross. Other good hybrids for earliness were CoBG 302 x CoBG 303, PDU 5 x VB 11, TAU 2 x CoBG 303 which had negative sca effects and were on par. Cross T 9 x VB 11 also had significant negative effect (Table 5.a and Fig. 1).

The better combinations for earliness therefore involved late x early, early x early and also late x late combining parents.

T 9 among lines and CoBG 303 among testers were found to be the best general combiners and PDU 101 x WBG 67 the best specific combiner (Table 8). As the character was mainly under the control of nonadditive gene action recombination breeding would be preferred for the improvement of this character.

5.2 Duration of the crop

Mean squares due to lines and line x tester were found to be significant suggesting both additive and nonadditive gene action in duration of the crop. The ratio of additive variance to dominance variance was less than unity (Table7) suggesting the importance of nonadditive gene action for the expression of the trait. Significance of both additive and nonadditive gene action with a predominance of nonadditive gene action was reported by Deshmukh and Manjare (1980) in mungbean, Patel *et al.* (1987) in pigeonpea and Singh *et al.* (1987) in blackgram. Nonadditive gene action for duration of the crop was reported by Salimath and Bahl (1985) and Jahagirdar *et al.* (1994) in chickpea, Kumar (1993) and Thiyagarajan *et al.* (1993) in cowpea.

Contrary to this, additive gene action was reported by Sandhu *et al.* (1981) in blackgram, Wilson *et al.* (1985) in greengram, Durong (1980) in soybean, Yadavendra and Sudhirkumar (1987) in chickpea, Chauhan and Joshi (1981), Patil and Bhapkar (1986), Thiyagarajan (1982) in cowpea and Mehetre *et al.* (1988) in pigeonpea.

The gca of two lines and one tester were found to be negatively significant for the trait (Table 5.a and Fig. 2). Among lines maximum negative gca was recorded by T 9 followed by PDU 101. Among testers only WBG 67 showed significant negative effect. Three hybrids showed significant negative sca effects. The maximum negative sca effect was shown by the cross PDU 101 x WBG 67 followed by TAU 2 x CoBG 303. The parents involved in these crosses were early x early and late x late general combiners. The best general combiners were T 9 among lines and PDU 101 among testers. The cross PDU 101 x WBG 67 was the best specific combiner (Table 8).

Since the character was predominantly under the control of nonadditive gene action improvement could be achieved through recombination breeding programme.

5.3 Leaf Area Index

For leaf area index (LAI) at 50 per cent flowering variance due to line x tester interaction was found to be significant (Table 4.a) suggesting the importance of sca effects for the trait. The ratio of additive to dominance variance was also found to be less than unity (Table 7) indicating the importance of nonadditive gene action. This was in accordance with the findings of Candra and Nijhawan (1979) and Sreekumar (1993) in greengram. Desmukh and Bhapkar (1982) in chickpea also reported similar result. Contrary to this, Kumar (1993) in cowpea reported the prevalence of additive gene action for the character. In sesamum Reddy and Haripriya (1990) found the importance of both additive and nonadditive gene action.

Highest gca for LAI among lines were shown by CoBG 302, PDU 5 and TAU 2. Among testers the value was highest for WBG 67 (Table 5.a and Fig. 3). All the crosses had significant sca values and higher values for sca was shown by PDU 5 x WBG 67, CoBG 302 x CoBG 303 and TAU 2 x VB 11.

This involved a cross of parents of positive x positive and two with positive x negative gca effects.

The best general combiner for this trait was CoBG 302 among lines, WBG 67 among testers. The best specific combiner was the cross PDU 5 x WBG 67 (Table 8). Since nonadditive gene action was predominant in these character recombination breeding would be the best method to improve the character.

5.4 Leaf thickness

Leaf thickness is an important character associated with drought tolerance. With the increase in thickness of leaves the capacity of plants to hold water and xerophytic nature of the plant increases.

Variance due to line x tester was significant in the case of leaf thickness indicating the importance of sca variance suggesting nonadditive gene action

(Table 4.a). Ratio of additive to dominance variance was also less than one confirming the nonadditive gene action (Table 7). No literature was found to support or contradict the result.

Among lines T 9 had positive and significant gca while tester, VB 11 had significant gca. The maximum sca was shown by the cross TAU 2 x WBG 67 followed by T 9 x VB 11 and PDU 101 x CoBG 303 (Table 5.a and Fig. 4). The parents involved in these crosses, one had negative x negative and two with positive x positive gca effects. The best general combiners were T 9 among lines and VB 11 among testers and the best specific combiners involved in the cross TAU 2 x WBG 67 (Table 8).

Since nonadditive gene action was predominant for this character further improvement could be done through recombination breeding.

5.5 Stomata per microscopic field

Stomatal resistance is important in water economy and in turn drought resistance. Lesser the number of stomata lesser the water loss through transpiration.

For number of stomata per microscopic field line x tester variance was found to be significant suggesting the importance of sca effect for the trait (Table 4.a). Ratio of additive to dominance variance was found to be less than unity indicating the importance of nonadditive gene action for the character (Table 7). No literature was available to support or contradict the result.

The individual gca and sca effects for the character is presented in Table 5.a and Fig. 5. Significant negative values for gca were shown by the lines TAU 2 and CoBG 302 and tester WBG 67. Maximum negative values for sca were shown by T 9 x WBG 67, PDU 101 x VB 11, TAU 2 x VB 11 and CoBG 302 x WBG 67. The hybrids were evolved from parents with positive x negative and negative x negative gca effects.

The best general combiners for this character were the line TAU 2 and the tester WBG 67. The best specific combiner was T 9 x WBG 67. Stomata per microscopic field was under the control of nonadditive gene action and therefore further improvement could be done through recombination breeding.

5.6 Root shoot ratio

Water stress increases the proportion of plant dry matter translocate to the roots compared to the leaves and stems, thus increasing the root shoot ratio for high yielding blackgram varieties at stress.

Mean squares due to line x tester was found to be significant for the trait indicating the importance of sca variance rather than gca variance with respect to the character (Table 4.a) which indicated the predominance of nonadditive gene action. The ratio of additive to dominance variance was found to be less than unity (Table 7) suggesting the predominance of nonadditive gene action for the character.

Sreekumar (1993) in greengram found that both gca and sca were significant with predominance of additive gene action for root shoot ratio. Significant positive gca was observed in line PDU 5 and tester WBG 67. Significant positive sca was shown by the cross CoBG 302 x CoBG 303. The cross was resulted from parents with negative gca values (Table 5.a and Fig.6).

The best general combiners among lines and testers were PDU 5 and WBG 67 respectively and best specific combiner was CoBG 302 x CoBG 303 (Table 8).

Root shoot ratio was found to be under the control of nonadditive gene action and therefore improvement would be possible through recombination breeding programme.

5.7 Spread of root at harvest

Root length and spread influence grain yield under stress condition by influencing water uptake in plants. A well developed and wide spread root system is characteristic of reduced drought injury and increased yield in crop plants.

For root spread line x tester mean square was found to be significant (Table 4.a) which indicated the significance of sca effect for the character. The ratio of additive to dominance variance was found to be less than one which also suggested the predominance of nonadditive gene action for the character (Table 7).

Nanga and Saxena (1986) in pearl millet and Rosaiah *et al.* (1994) in greengram reported nonadditive gene action for root length. On the other hand, Islam *et al.* (1987) in mungbean reported additive gene action for root spread.

The gca and sca effects are presented in table 5.a and fig. 7. Among lines CoBG 302 had significant positive gca while WBG 67 among testers had significant positive gca. Among crosses PDU 101 x WBG 67, T 9 x VB 11, PDU 5 x CoBG 303 and CoBG 302 x CoBG 303 had significant positive sca. This involves crosses of parents with negative x positive, negative x negative gca and two with positive x negative gca effects.

The best general combiners were CoBG 302 in lines and WBG 67 in testers. The cross PDU 101 x WBG 67 was the best specific combiner (Table 8).

Since the character is predominantly under the control of nonadditive gene action further improvement could be done through recombination breeding.

5.8 Proline content

Accumulation of proline during stress is considered to be an adaptive mechanism for drought tolerance. Proline considerably increases the amount of bound water in leaves, thereby enhancing the leaf water potential. Maximum proline accumulation is usually observed in varieties having more drought tolerance (Pandey, 1982).

Proline content showed significant variance in line x tester so only sca variance was significant indicating the importance of nonadditive gene action for the character (Table 4.a). The ratio of additive to dominance variance was less than one which also confirms the above view (Table 7).

Nonadditive gene action was reported by Kumar (1993) in cowpea but both additive and nonadditive gene action with a predominance of nonadditive gene action was reported by Sreekumar (1993) in greengram.

The line, T 9 showed positive significant gca and the tester, VB 11 showed maximum significant gca. Significant sca effects were shown by CoBG 302 x CoBG 303, PDU 5 x WBG 67, PDU 101 x VB 11, T 9 x CoBG 303 and TAU 2 x VB 11. Three of the crosses involved parents with positive gca and one with negative gca and one with positive x negative gca (Table 5.a and Fig. 8).

The best general combiners were T 9 among lines and VB 11 among testers and best specific combiner CoBG 302 x CoBG 303 (Table 8).

Since nonadditive gene action was predominant for the character recombination breeding programme would be best suited for its improvement.

5.9 Height of the plant

Height of the plant is positively correlated with yield in pulses. For height of the plant, line x tester interaction was significant suggesting the importance of sca effect for the trait (Table 4.b). The ratio of additive to dominance variance was also found to be less than unity, which also emphasised the importance of nonadditive gene action in this character (Table 7).

This was in accordance with the findings of Rajarathinam and Rathnaswamy (1990) in blackgram and Naidu and Satyanarayana (1993) in greengram. However Sagar and Chandra (1977) in blackgram reported additive gene action for plant height.

Table 5.b and Fig. 9 give the sca and gca effects with respect to height of the plant. Only the line, PDU 5 had positive and significant gca for height of the plant. The line PDU 101 also had positive gca effects but was not

significant. Testers did not show any significant positive gca. Highest positive gca was shown by VB 11. Maximum significant sca was shown by the cross PDU 101 x WBG 67 followed by T 9 x VB 11. This involved parents with positive x positive and negative x positive gca respectively.

The best general combiners in lines and testers were PDU 5 and VB 11 respectively and the best specific combiner PDU 101 x WBG 67 (Table 8). Since the character was predominantly under the control of nonadditive gene action further improvement could be possible through recombination breeding.

5.10 Number of branches per plant

For the character number of branches per plant nonadditive gene action was predominant since the ratio of additive to dominance variance was less than one (Table 7).

Nonadditive gene action was reported by Naidu and Satyanarayana (1993) in greengram, Jahagirdhar *et al.* (1994) and Mishra and Yadav (1994) in chickpea, Thayagarajan *et al.* (1993) in cowpea. Contrary to this additive gene action was reported by Singh *et al.* (1994) in sweetpea.

Testers, lines and crosses did not show any significant gca or sca effect.

5.11 Number of pods per plant

Plants which produce more pods per plant along with more seeds per pod would be desirable to get higher production.

As evident from the Table 4.b significant difference in mean squares for lines and line x tester was noticed in number of pods per plant. This indicated the significance of gca and sca. Thus both additive and nonadditive gene actions were involved. However nonadditive gene action seem to be predominant since the ratio of additive to dominance variance was less than one (Table 7).

For number of pods per plant significant positive gca was shown by the line T 9 while in tester it was shown by WBG 67. The cross PDU 101 x WBG 67 and T 9 x VB 11 showed significant sca (Table 5.b and Fig. 11). These crosses involved parents with negative x positive and positive x negative gca effects respectively. The best general combiner among lines and tester were T9 and WBG 67 respectively and best specific combiner PDU 101 x WBG 67 (Table 8).

As the character was mainly under the control of nonadditive gene action recombination breeding would be preferred for its improvement.

5.12 Number of seeds per pod

In number of seeds per pod mean square of line x tester was significant (Table 4.b) which indicated the significance of sca variance. Also the ratio of additive to dominance variance was less than one (Table 7). Thus nonadditive gene action was predominant for the character seeds per pod.

Additive and nonadditive gene actions with a predominance of nonadditive gene action was reported by Chowdhury (1986) and Natarajan *et al.* (1990) in greengram, Singh *et al.* (1987) in pea and Sharma and Nishisharma (1988) in soybean. Predominance of nonadditive gene action alone was reported by Pande *et al.* (1979) in chickpea, Sagar and Chandra (1977) and Rajarathinam and Rathnaswamy (1990) in blackgram, Deshmukh and Manjare (1980), Natarajan (1990) and Naidu and Satyanarayana (1993) in greengram, Dhillon and Chahal (1981) in pea, Zaveri *et al.* (1983) and

Thiyagarajan *et al.* (1990) in cowpea and Das and Dana (1981) in rice bean, while additive gene action was reported by Chauhan and Joshi (1981) and Thiyagarajan (1992) in cowpea, Wilson *et al.* (1985) in greengram, Venkateswarlu and Singh (1981) and Singh *et al.* (1983) in pigeonpea while Dubey *et al.* (1983) in pea, Singh and Singh (1993) in lentil, it was also reported by Mishra and Yadav (1994) in chickpea, Saxena and Sharma (1989) in greengram and Durong (1980) in soybean.

Significant gca among lines were shown by PDU 101 and PDU 5 and in testers by WBG 67. Significant sca were shown by the crosses PDU 5 x VB 11, T 9 x CoBG 303 and PDU 101 x CoBG 303. The crosses were the result of parents with four negative x negative and two with positive x negative gca effects (Table 5.b and Fig. 12).

Since the character was predominantly under the control of nonadditive gene action improvement could be achieved through recombination breeding programme.

5.13 Grain yield per plant

Involvement of both gca and sca were revealed from the analysis of variance for grain yield since the lines and line x tester interaction had significant mean squares as evident from the Table 4.b.

The character grain yield was therefore found to be controlled by both additive and dominant gene actions. But the predominance of nonadditive component was expected since the ratio of additive to dominance variance was less than than unity (Table 7). This was in accordance with the findings of Deshmukh and Manjare (1980), Haque *et al.* (1988), Naidy and Satyanarayana

(1993) and Rosaiah *et al.* (1994) in greengram, Singh *et al.* (1987) and Kaliya *et al.* (1991) in blackgram, Thiyagarajan *et al.* (1993) and Kumar (1993) in cowpea, Pande *et al.* (1979) Katiyar and Katiyar (1993), Mishra and Yadav (1994), Yadavendra and Sudhirkumar (1987) and Bhal and Kumar (1989) in chickpea. Both additive and nonadditive gene action was reported by Chowdhury (1986) in mungbean and Mishra *et al.* (1987) in cowpea. However additive gene action was reported by Malhotra (1983) in blackgram. Wilson *et al.* (1985), Saxena and Sharma (1989), Natarajan *et al.* (1990) and Saxena and Sharma (1992) in greengram and by Singh and Saini (1986) in frenchbean.

Significant positive gca effect among lines for grain yield per plant was shown by T 9 only. While in tester WBG 67 alone showed significant positive gca (Table 5.b Fig.13). Significant positive values for sca were shown by six hybrids PDU 101 x WBG 67, CoBG 302 x CoBG 303, T 9 x WBG 67, TAU 2 x VB 11, TAU 2 x CoBG 303 and PDU 101 x VB 11. Among these one involved parents with gca of negative x positive, four with negative x negative and one with positive x positive effects.

The best general combiner among lines was T 9 and testers WBG 67. The best specific combiner was PDU 101 x WBG 67 for this character (Table 8).

Since the character grain yield was predominantly under the control of nonadditve gene action further improvement of the character could be achieved through recombination breeding.

5.14 Hundred seed weight.

Plants having a seed weight of 3.5 - 4.0 gram per hundred seeds may be preferred for an ideal plant type (Dhanpal Singh , 1991)

The sca variance was significant for hundred seed weight since the mean square due to line x tester was significant (Table 4.b) indicating the importance of nonadditive gene action. The ratio of additive to dominance variance also was less than one suggesting the significance of dominance gene action for the expression of the character (Table 7). Prevalence of nonadditive gene action was already reported by Malhotra (1983) and Sood and Garten (1991) in blackgram, Katiyar *et al.* (1988) in chickpea, Thiyagarajan *et al.* (1990), Sreekumar (1995) and Thiyagarajan *et al.* (1993) in cowpea, Singh and Singh (1993) in Lentil and Naidu and Satyanarayana (1993) in mungbean. Contrary to this gene action was reported by Sandhu *et al.* (1981) in blackgram, Wilson *et al.* (1985) and Rosaiah *et al.* (1994) in greengram, Singh *et al.* (1975) in gram, Kumar (1993) and Sawant (1995) in cowpea, Yadavendra and Sudhirkumar (1987) in chickpea Venkateswarlu and Singh (1981) and Dubey and Lal (1983) in pea and Patel *et al.* (1987) in pigeonpea.

For hundred seed weight , maximum positive significant gca among lines was shown by PDU 101 and PDU 5. Among testers significant positive gca was shown by WBG 67 (Table 5.b and and Fig.14) Among the crosses significant sca was shown by PDU 101 x WBG 67 followed by TAU 2 x VB11, positive significant effects were also shown by CoBG 302 x CoBG 303, PDU101 x CoBG 303, T 9 x WBG 67, PDU 5 x WBG 67 and PDU 5 x VB11.

The best general combiner among lines was PDU 101 and among testers WBG 67 and the best specific combiner was PDU 101 x WBG 67 (Table 8).

Recombination breeding would be a suitable proposition to improve the character as it is controlled predominantly by nonadditive gene action.

5.15 Seed protein content

For seed protein content sca effect alone were found to be significant since line x tester interaction alone was significant (Table 4.b) which indicated the importance of nonadditive gene action. This fact was further emphasised by the ratio of additive to dominance variance which was found to be less than one (Table 7). Thus the character was found to be controlled by nonadditive gene action.

Nonadditive gene action for seed protein was reported by Rosaiah *et al.* (1994) in greengram, conversely additive gene action was reported by Naidu and Satyanarayana (1993) and Sandhu *et al.* (1994) in greengram for the character.

As revealed by the Table 5.b and Fig. 15 the maximum positive gca effect among lines was shown by PDU 5 followed by PDU 101. Among testers positive significant value was shown only by VB 11. Among hybrids maximum sca was shown by PDU 101 x WBG 67 followed PDU 5 x CoBG 303, CoBG 302 x CoBG 303, TA 2 x VB 11, PDU 5 x VB 11.

The best general combiner among lines was PDU 5 and among testers was VB 11. The best specific combiner for the trait was PDU 101 x WBG 67 (Table 8).

The character seed protein content was predominantly under the control of nonadditive gene action. So further utilization could be done through recombination breeding.

5.16 Harvest index

Line x tester mean square for harvest index was found to be significant indicating greater importance of sca variance in the character (Table 4.b). This emphasised the role of nonadditive gene action.

The ratio of additive to dominance variance was less than one (Table 7) Thus nonadditive gene action was found to be predominant for harvest index.

This is in accordance with the findings of Salimath and Bahl (1988) in chickpea and Katiyar *et al.* (1987) in pea. Both additive and nonadditive effects were reported by Hazarika *et al.* (1988) in pigeonpea and Patel *et al.* (1988) in mungbean. However, additive gene action was reported by Pande *et al.* (1979) in bengalgram. Singh *et al.* (1987) in blackgram and Saxena *et al.* (1989) in pigeonpea.

Table 5.b gives the individual gca and sca effects for harvest index in the lines, testers and the hybrids and are presented in the Fig. 16. Maximum positive gca for Harvest Index was shown by two lines PDU 5 and T 9 while VB 11 among testers showed significant positive gca.

The hybrid PDU 101 x WBG 67 had maximum significant positive sca followed by CoBG 302 x CoBG 303 and T 9 x WBG 67. These involved parents of negative x negative and negative x positive gca effects. Majority of the crosses with positive sca were from parents with negative x positive gca effects.

Best general combiner among line was PDU 5 and among testers was VB 11 while the specific combiner was the cross PDU 101 x WBG 67 (Table 8).

The character harvest index was controlled by nonadditive gene action so recombination breeding for improvement would be recommended in this case also.

With respect to the mean performance, the line PDU 5 was the best in three drought and two yield related characters. TAU 2 proved to be the best in two each of drought and yield characters, the lines CoBG 302 was the best in three yield characters and T 9 in three drought characters. The cross PD 101 x WBG 67 turned out to be the best in one drought and three yield related characters, while T 9 x WBG 67 in one drought and two yield characters.

In the case of combining ability effects, the line T 9 was the best in four each of drought and yield related characters, and CoBG 302 in three drought related characters. The tester WBG 67 was the best in five each of drought and yield characters, while VB 11 proved to be the best in two drought and three yield characters. The cross PDU 101 x WBG 67 was the best in three drought characters and seven yield characters. Thus this cross was found to be the best in mean performance and sca effects. In addition to this the crosses CoBG 302 x CoBG 303 and T 9 x VB 11 also showed higher sca value in the case of large number of characters (Table 9).

Lines contributed maximum to the total variance for the characters duration of the crop, height of the plant, number of pods per plant, seed yield per plant and harvest index (Table 6 and Fig. 17).

Testers contributed maximum for the leaf area index, stomata per microscopic field and seed protein content. While crosses contributed maximum for days to 50 per cent flowering, number of branches per plant, number of seeds per pod, hundred seed weight, leaf area index, leaf thickness, number of stomata per microscopic field, root shoot ratio, spread of root, proline content and seed protein content. For most of the characters the lines and line x tester are having maximum contribution compared to the testers.

SUMMARY

SUMMARY

Blackgram is an important pulse crop in summer rice fallows in Kerala when moisture stress is a problem and irrigation facilities are very low. Developing high yielding drought tolerant varieties, is therefore imperative. The present study was taken up with the objective of generating information on general and specific combining ability and gene action for drought tolerance, yield and their components which will help in improving the yield potential under moisture stress conditions.

The experiment was conducted in the Department of Plant Breeding, College of Agriculture, Vellayani, during 1996-97. Based on yield and drought tolerance, eight varieties were selected as parents - Five drought tolerant lines and three high yielding testers. Hybridization was done between the five lines and three testers. The fifteen F1 hybrids along with eight parents were evaluated in RBD with three replications. The observations were recorded on days to fifty per cent flowering, duration of the crop, leaf area index, leaf thickness, stomata per microscopic field, root shoot ratio, spread of root, proline content, height of the plant, number of branches per plant, number of pods per plant, number of seeds per pod, grain yield per plant, 100 seed weight, seed protein content and harvest index.

Analysis of variance indicated significant differences among treatments for all the characters. Difference among parents were observed for all the traits except number of branches per plant and number of pods per plant indicating that the parents were genetically divergent for all except these two characters. Significant difference were observed among crosses for all the characters and hence gene action and combining ability were estimated for all the traits. The character leaf hairiness was uniformly medium for all the parents and crosses.

The characters, number of pods per plant, seed yield per plant and duration of the crop showed significant difference among lines. For these three characters the gca variance was significant. Line x tester interaction had significant effect for all the characters except number of branches per plant, indicating the importance of sca variance.

Combining ability analysis had shown that both gca and sca variance were significant for number of pods per plant, seed yield per plant and duration of the crop, indicating the involvement of both additive and non additive gene action. In all these characters the ratio of σ^2 gca and σ^2 sca was found to be less than unity, indicating the predominance of non additive gene action, for these traits.

For characters days to 50 per cent flowering, LAI, leaf thickness, stomata per microscopic field, root shoot ratio, spread of root, proline content, height of the plant, number of seeds per pod, 100 seed weight, seed protein content, and harvest index, line x tester interaction alone was significant indicating that these characters were mainly governed by nonadditive gene action. The ratio of gca to sca variance was also less than unity thus confirming the result. For number of branches per plant the L, T and L x T were not significant but the ratio of additive to dominance ratio was less than one suggesting non additive gene action.

Based on gca effects alone it was difficult to choose good general combiners for all the characters together. Similarly no cross combination was observed to be good for all the characters. Certain parents were found to be good for certain traits. Among lines T9 was the best for various yield and drought related characters such as days to 50 per cent flowering, duration of the crop, leaf thickness, spread of root, height of plant, number of branches per plant, grain yield per plant and harvest index.

Among testers WBG 67 and VB 11 were identified as good parents which had better gca for most of the yield and drought tolerance factors. They can be used in future breeding programme.

Among crosses, PDU 101 x WBG 67 was the best specific combiner for yield and drought tolerance. It also turned out to be the best in the mean performance of various traits. It was folowed by CoBG 302 x CoBG 303 and T 9 x VB 11.

Since the study in general indicated the predominance of non additive gene action, recombination breeding could be resorted to for the improvement of blackgram for yield, drought tolerance and selected characters.

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COMBINING ABILITY FOR DROUGHT TOLERANCE AND YIELD IN BLACKGRAM

(*Vigna mungo* (L.) Hepper)

By

ROY ISAAC VARGHESE

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COLLEGE OF AGRICULTURE
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ABSTRACT

A research programme consisting of five drought tolerant lines, three high yielding testers and their fifteen hybrids was carried out at the Department of Plant Breeding, College of Agriculture, Vellayani, during 1996-97, to evaluate the combining ability and gene action for drought tolerance, yield and related characters in blackgram. The lines and testers were selected based on previous performance and crossed and subjected to line x tester analysis and data recorded on both yield and drought related characters. Significant difference among the treatments was observed for all characters. Differences among parents were observed for all characters except number of branches per plant and number of pods per plant. Crosses were significantly different for all the characters. Therefore combining ability analysis was carried out for all characters. Specific combining ability variance was significant for all traits except number of branches per plant indicating the importance of non additive gene action. Both additive and non additive gene action were found to be involved for duration of the crop, number of pods per plant and grain yield per plant. However in all cases non additive gene action was predominant.

Among lines, T 9 emerged as the best general combiner for various yield and drought related characters. The line, CoBG 302 was also found to be a better general combiner for various characters. Among testers, WBG 67 proved to be the best general combiner followed by VB 11. No specific cross combination was found to be significantly different for all the traits together. However the cross PDU 101 x WBG 67, CoBG 302 x CoBG 303 and T 9 x

VB11 were found to be the better specific combiner, when all the characters are considered.

In short on the basis of combining ability estimated the lines T 9 and CoBG 302, the testers WBG 67 and VB 11 and the hybrids PDU 101 x WBG67, CoBG 302 x CoBG 303 and T 9 x VB 11 were suggested for further utilization for improvement.